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PAPERS AND PROCEEDINGS OF

THE ROYAL SOCIETY OF TASMANIA

Edited by M. R. Banks and M. J. Brown

and Published by the Society

Hobart

Tasmania

30 JUNE 1996

VOLUME 130 • PART 1

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Museum Victoria
71387

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Her Majesty the Queen

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General Sir Phillip Bennett AC, KBE, DSO to 1 October
His Excellency the Governor of Tasmania
Sir Guy Green AC, KBE from 2 October

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PAPERS AND PROCEEDINGS OF THE ROYAL SOCIETY OF TASMANIA
VOLUME 130(1)

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ROYAL SOCIETY OF TASMANIA
Annual Report for the Year 1995

The Council has the honour to present to members the following report on the activities of the Society during the year.

Council and Office Bearers

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Honorary Assistant Editor
Dr Mick Brown

President

His Excellency General Sir Phillip Bennett took the chair as President of the Society at the Annual General Meeting of the Society and that of the Northern Branch. He also took the chair at a meeting at Government House, Hobart, on 8 June, during which the Society bid him farewell. At this meeting Vice-President Dr Penny McCartney drew attention to the considerable interest which Sir Phillip had taken in the activities of the Society, made presentations of farewell gifts to Lady Bennett and the President and, on behalf of the Society, wished them well in their retirement.

Sir Guy Green graciously accepted an invitation to become President and was formally welcomed to that position by Dr McCartney at a meeting of the Society in the new Royal Society Lecture Theatre in the Custom House, Hobart, on 21 November. As President, he then formally opened the new lecture theatre.

Deaths

The deaths of the following membes are recorded with regret:

Mr J.H. Buckley (Northern Branch, member since 1967)
Mrs L.J. Clark (member since 1976)
Dr G. Dick (member since 1968)
Mr I.S. Lea (member since 1970)

Honours and Awards to Members

Dr W.M. Curtis AM was awarded the Mueller Medal for Science for 1995 by the Australian and New Zealand Association for the Advancement of Science. This medal, one of the most prestigious science awards in Australia, was awarded to Dr Curtis in recognition of the major contribution she has made to research on Tasmanian plants during a period of over 50 years. She became a member of the Society

in 1940, received the Clive Lord Memorial Medal from the Society in 1966 and was honoured by the Society by the publication of *Aspects of Tasmanian Botany* in 1991, a tribute from botanists in Tasmania, other parts of Australia and overseas.

Membership

The membership is 445, a decrease of 30 relative to 1994 and is made up as follows:

President	1	
HonoraryMembers	7	(2)
Life Members	32	(10)
Ordinary Members		
receiving *P. & P.*	272	(46)
not receiving *P.&P.*	111	(41)
Associate Members	22	(7)
Total	445	(106)

Figures in brackets are those for the Northern Branch.

Staff

Ms Vicki Farmery contracted to provide administrative and secretarial services to the Society during 1995. She has provided these effectively, at times under difficulties, and the thanks of the Society are extended to her.

Procedural Guide

A "Procedural Guide and Administrative Diary" were completed after consultation with Councillors and others concerned with the administration of the Society. The help of Mr Don Gregg, formerly Honorary Secretary, is particularly acknowledged. These documents should facilitate the activities of office bearers and others concerned with the administration of the Society.

Council Meetings

There were six Council Meetings during the year. Matters which were of particular concern to Council included the establishment of a Foundation, a review of assets especially the Royal Society Art Collection, the sale of assets in excess of those needed by the Society (chairs, volumes of *Papers and Proceedings* and other publications, and duplicates of books in the Society's library), the new Royal Society Lecture Theatre and other facilities in the Custom House, purchase of new equipment to improve facilities available to members, and changes to the Rules of the Society to improve the efficiency of administration of the Society. An agreement with the Tasmanian Division of ANZAAS concerning a joint symposium and publication was negotiated.

The Royal Society of Tasmania Foundation

The constitution of the Foundation was established at the General Meeting on 4 April and the Foundation met first on 10 August. The Foundation is chaired by Mr R.T. Banks with Dr M. Banks as Secretary (*ex officio*) and members Dr D.E. Leaman, Mr D. Langoulant. Dr J.C.H. Morris and Dr J.G. Thorne. The Foundation was launched officially by Hon. R.J. Beswick, Deputy Premier and Minister for Education and the Arts, on 21 November in the new Royal Society of Tasmania Lecture Theatre.

Members began to make donations to the Foundation late in November and over $2500 had been received by the end of the year.

The Royal Society of Tasmania Art Collection

In October a group of volunteers (Mr G.D. Brown, Mr R. Lord, Mrs J. Parrott and Dr I. Skira) under the guidance of Dr Tony Brown began the work of checking information on the Society's art collection which is on long-term loan to the Trustees of the Tasmanian Museum and Art Gallery. This work was well advanced by the end of the year.

Sales of Assets

Chairs, formerly in the Royal Society Room, were offered for sale to members during the year and some were purchased. Volumes of *Papers and Proceedings* and other publications from the stocks of the Society were offered to members in the first half of the year and some hundreds were purchased. Late in the year, duplicate volumes from the Society's library were made available for purchase by members before being offered (in 1996) at public auction. Eight members took advantage of the opportunity.

The total sum resulting from these sales was of the order of $7000 which will be transferred to the Foundation.

New Society Facilities

Late in 1995, new facilities became available to members of the Society when the Tasmanian Museum and Art Gallery was able to occupy the Custom House in Davey Street. Needs of the Museum associated with the move had earlier led to shortage of room in the Museum buildings and the Society allowed the Museum to use the Royal Society Room for purposes which precluded use as a lecture room. The Society met in other rooms in the Museum.

The new facilities in the Custom House include a lecture theatre, a small lounge (to be shared with the Friends of the Museum), an office (also shared) and part of a kitchen, a distinct improvement on earlier facilities. In these new facilities are a suite of furniture and a lectern commissioned from furniture designer Peter Costello under the "Art in Public Places" Program after consultation between Ms P. Sabine and members of the Room Committee of Council. The Society Honour Board was brought up to date and a plaque with some historical material added. The updated Board was placed in the new theatre together with photographs of earlier Royal Society Rooms and a plan showing previous locations. A lapel microphone and associated equipment was added to Society facilities during the year as well as a number of cups and saucers. The new theatre is proving popular.

Council thanks the Trustees of the Museum and Art Gallery for making these new facilities available as a replacement for the former Royal Society Room.

Changes to the Rules and Practices

Changes to the Rules leading to the use of inclusive language, to simplification of the nomination and election process and to better control of income from subscriptions were passed late in the year. A change in design and the timing of dispatch of the subscription invoices to members resulted in greater efficiency in this area.

Honours Committee

A committee was set up by Council to make recommendations concerning awards. The Committee, consisting of Dr Shirley Jeffrey AM (Convener), Mr David Hannan, Professor Jim Reid and Professor Michael Roe, made recommendations, the result of which will be announced at the Annual General Meeting in March 1996.

Grants to the Society

Council received support from the State Government in the form of a special grant of $3000 towards the cost of the Society's publication programme and through Arts Tasmania, a grant of $2000 towards the administration and promotion of the Society.

The publication programme was also supported by a grant of $3000 from the University of Tasmania.

The Society acknowledges receipt of these grants with thanks and appreciates the support implied by them.

Library

Progress in the slow but steady integration of information on the Library collections into the University on-line catalogue continued during the year. This work has concentrated on the current serials collection and the rare books.

During the year a significant project was undertaken to identify duplicate items held by the Library. As a result of this exercise, a list of duplicate titles was provided to the Society for investigation and analysis with a view to possible disposal. Subsequently, records for titles to be withdrawn required annotation and the Library Assistant was involved with the inspection of titles listed for eventual disposal.

Arrangements for the lending of serial volumes was further streamlined during the year, the significant change being in the loan period. Serial volumes now being lent are issued for the same period as University loans, thereby reducing confusion for those who borrow from both collections. Issues are channelled through the Morris Miller Library loans desk where the material can be adequately processed and security maintained.

Binding processes continue to function adequately, the Library having part of the Morris Miller annual quota. Over 40 volumes were bound during 1995.

Volume 129 of the *Papers and Proceedings* was despatched to exchange partners using, for the last time, the mailing database housed on the University Library database. From 1996 onwards, the mailing list will be maintained on the Library Assistant's personal computer and will be used to generate mailing labels when volumes are ready for dispatch. This process allows updating more readily than hitherto.

Space problems continue to create some difficulty, particularly as a result of the reclassification and re-shelving programme. Consideration is being given to significant re-shelving on level 5 of the Morris Miller building, which should result in a more workable arrangement for the collection and easier integration of new and reclassified titles.

Use of the Royal Society Archives was significant during the year, with 78 users recorded as making 187 consultations. Notable during the year was a re-examination of the Walker papers in relation to Aboriginal anthropology, and work relating to Cape Barren Island and John Woodcock Graves. Proof foils for the Royal Society seals and minutes for the 1970s were deposited in the Archives during 1995. Installation, during the year, of a computer-controlled air conditioning unit and reduced ultra-violet lighting units now provide maximum protection for archival material. Some assessment of the condition of archival material and rare books has been undertaken.

In the latter part of the year, the Library was able to provide a significant contribution to a University Library display of material on butterflies. The principal source of the material was the collection of Leonard Couchman, which the Society acquired in 1992. The Society was also able to provide material on James Cook for a display in the Archives reading room.

Staffing for the Library was maintained throughout 1995 as for the previous year, with, however, increased flexibility between the staff available to the Librarian. Carol Freeman continues to undertake the day-to-day running of the Library with the assistance, as and when required, of Judy Jeffery and Emilia Ward. The resultant multi-skilling has led to a notable degree of flexibility in staff activity and has allowed a number of labour intensive tasks to be undertaken quickly and efficiently.

Statistics for Library use during the year are as follows: Consultations 81; loans 80; visitors 212. These figures are minima, derived from signatures in the appropriate registers which, however, many users omit to sign.

Council thanks Mr Graeme E. Rayner, Morris Miller Library, University of Tasmania, who was responsible for the Society Library during the year.

Publications

Volume 129 of the *Papers and Proceedings* was published late in June. In addition to the Annual Report for 1994, the volume contains nine papers involving 13 authors from Tasmania, other parts of Australia and overseas. The papers deal mainly with Tasmania but include one on Heard Island and one on Antarctica. The subject areas were botany, palaeobotany, glacial history, and zoology.

Mrs Alison Jones acted as sub-editor and Mrs June Pongratz prepared the volume for publication. Their expert assistance is gratefully acknowledged.

Work started on a joint publication with the Tasmanian Division of ANZAAS based on a joint symposium held in November on climatic history (see "Events").

Events in 1995

7 March (Annual General Meeting) — "Amateurs and the Royal Society in the accumulation of geological knowledge in Tasmania" Dr Max Bank, Vice-President

20 March — "Earthwatch and the Rocky Mountains Wildflower Project" Mr Peter Stevenson, member of the Society

4 April — "Tempting Asian tastes and capturing new opportunities for primary producers in Tasmania" Mr Steve Martin, Dep. of Primary Industry and Fisheries.

2 May — "Town Planning in retrospect" Mr Keith Tyler, former Commissioner for Town and Country Planning

15 May — "The electronic super-highway — what it might mean for you" Mr Eddy Steenbergen, Chairman, Tasmanian Branch, Australian Computer Society

25 May — "Different forms of signalling employed by the nervous system" Professor John Nicholls FRS, University of Basl; joint with University of Tasmania

8 June (at Government House, the President in the Chair) — "The demise of the Dinosaurs III. Were the extinctions global?" Dr Lin Sutherland, Australian Museum; with a farewell to the President, Sir Phillip Bennett, and Lady Bennett and presentation to them by Vice-President Dr Penny McCartney

27 June — "The self-made brain" Professor Colin Blakemore, FRS, University of Oxford; joint with the University of Tasmania

4 July — "The reproductive biology of the Tasmanian bettong" Dr Randy Rose, University of Tasmania, Hobart

1 August — "Symposium on Antarctic topics" introduced by Professor Garth Paltridge, Antarctic Co-operative Research Centre, University of Tasmania, Hobart, with talks by students at the Centre
"The emission of microwave radiation from snow" Mr Jeremy Cotton
"Sulphate-reducing bacteria in the lakes of the Vestfold Hills" Ms Suzy Rea
"Mean Southern Ocean circulation from hydrographic data" Mr Jeremy Harris
"The significance of overlapping regimes and their impact on International relations" Mr Edmund Chia

5 September — "Progress in the development of marine oil products in Australia" Dr Peter Nichols, CSIRO, Hobart

3 October — "Who remembers Wau and Salamaua? A veteran returns to the battlefields of Papua New Guinea with a group of Tasmanian Army officers" Lt Col. Peter Hodges (Ret'd)

7 November — "Aid, Asia, and agriculture" Mr Ian Geard, agricultural consultant for EU, UN Development Bank and World Bank

9 to 11 November — Seminar and workshop "Climate succession and glacial history of the Southern Hemisphere over the past five million years" organised by a committee, Professor Pat Quilty (Convener); joint with the Tasmania Division of ANZAAS

21 November — Welcome to Sir Guy Green, new President, by Dr Penny McCartney, Opening of the new Royal Society Lecture Theatre by Sir Guy Green and launch of the Royal Society of Tasmania Foundation by Hon. R.J. Beswick, Deputy Premier

30 November — Tour of the Moorilla Winery followed by dinner at the Winery Restaurant.

Attendance at functions ranged from 12 to 115. The programme of events for the year was arranged by Dr John Thorne (Convener, Programme Committee).

Northern Branch

Branch Council

Chairman	Mr Elvin Fist
Vice-Chairman	Mr John Kolkert
Past-Chairman	Mrs Mary Cameron
Honorary Secretary	Mr Chris Tassell
Honorary Treasurer	Mrs Doreen Girvan
Council Members	Mr Athol Beswick
	Miss Alison Green
	Ms Judith Hollingsworth
	Professor Campbell Macknight

The Council met five times during the year.

Meetings and Lectures

3 March — Annual General Meeting chaired by the President, His Excellency Sir Phillip Bennett, Governor of Tasmania; "Current issues in the fishing industry" Professor Nigel Forteath, Director, National Key Centre for Teaching and Research in Aquaculture, University of Tasmania, Newnham

7 April — members were encouraged to attend the Launceston Historical Society's John West Memorial Lecture on that evening

5 May — "Dairy heritage of northern Tasmania" Mrs Jill Cassidy, Oral Historian, Queen Victoria Museum and Art Gallery; joint with Friends of the Queen Victoria Museum

2 June — "Ross River disease in Tasmania" Dr Tim McManus, veterinarian, Department of Primary Industry and Fisheries, Falmouth

7 July — Members' Night
"New Education Fellowship 1915-1978" Mr Stan Payne
"Unknown Photographs" Mr Alan Orr
"History of the Launceston Competitions" Mr Peter Webb

4 August — "History of cheese making at Ashgrove" Ms Jane Bennett, Director, Ashgrove Cheese Factory

1 September — "History of Tasmanian photography" Mrs Rhonda Hamilton, Curator of Community History at the Queen Victoria Museum and Art Gallery

6 October — Panel presentation by students in the School of Humanities, University of Tasmania, Newnham
"A Tasmanian family" Ms Jane Waite
"The life and times of Frank Woodward" Mr Mike Powell
"Tasmanian Vietnam veterans" Mr Peter Henning

3 November — "The *Iron Baron* Mishap" Capt. Charles Black, Harbour Master, Port of Launceston Authority and co-ordinator for the clean up from the ship *Iron Baron*

1 December — Members' Night
"The Monds Family" Mr Jack Branagan
"Invertebrate Stowaways" Miss Alison Green
"Distance is a factor in Tasmanian life" Ms Judith Hollingsworth

Excursions
22 April — Visit to the Hollybank Forest with a guided tour by the Hollybank Forest Advisory Committee
30 September — Excursion to the Ashgrove Cheese Factory at Elizabeth Town.

Nominees to other Bodies

Tasmanian Museum and Art Gallery

Council elected Dr A.V. Brown and Professor J.B. Reid to serve on the Board of Trustees for 1995. These Trustees arranged for Ms P. Sabine, Director, to report on the year's activities as follows.

Operations
1995 was a significant year for the TMAG. A 99-year lease for the Custom House was signed by the Commonwealth and State governments on behalf of the Trustees of TMAG. For the first time all the building stock on the block bounded by Argyle, Macquarie, Dunn and Davey Streets comes under the one authority.

The lease was signed in February, work was commenced on the refurbishment under the architects Forward, Viney and Woollan, and builders Hansen & Yunken. As Stage 1 in the ten-year redevelopment, the Custom House includes office and lounge space shared between the Royal Society of Tasmania, the Friends of the TMAG and The Art Foundation. It also includes the Royal Society's Lecture Theatre.

Refurbishment was completed by the end of October and the Custom House was officially opened on 22 November by the Premier, Hon. Ray Groom MHA. As the Custom House remains under the ownership of Australian Estate Management and is overseen by the Australian Heritage Commission, all refurbishment work had to meet Commonwealth heritage preservation guidelines. Staff began to move into the Custom House in November.

Public Programs
Highlights of the 1995 exhibition program included:
• "Colonial Pastimes to Contemporary Profession — 150 years of Australian Women's Art" The exhibition taken solely from the TMAG collection extended over five galleries. It was one of a series of 126 linked exhibitions around the nation.
• "IBM Mathematica" — a travelling exhibition from the National Science Centre, Canberra, designed to communicate the history, fun and challenge of mathematics.
• "The Derwent Collection" — an exhibition of contemporary Australian art collected over ten years by a group of Hobart art enthusiasts.
• "The Meaning of Dress and Tasmanian Glass" explored items from the Decorative Arts Collection.
• "Otto Dix —The Critical Graphics" from the Goethe Institute.
• 1994 Moet and Chandon Award.
• To recognise the Australia Remembers 1945–95 year, an exhibition entitled "Australia Remembers — Eric Waterworth and the Optical Annexe" was opened in August and another entitled "Australia Remembers: Aboriginal Warriors 1788–1995" in November.
• The Australia Remembers Year was also significant for the partnership which developed with the Newspapers in Education Section of *The Mercury*. This program was supported by the State Committee for Australia Remembers, with funds from the Department of Veterans' Affairs. TMAG employed Roberta Poynter to develop a curriculum wall chart and an education kit for Tasmanian schools. Designed to focus on Tasmania's contribution to the war effort at home and abroad, the products were also marketed in Queensland, South Australia and Western Australia.
• "To Hell and High Water" was shown over January/February to celebrate 50 years of the Sydney to Hobart Yacht Race, jointly produced by the National Maritime Museum of Australia and TMAG, with considerable assistance from private lenders.

School Holiday Program
The school holiday program was reinstated with curators and others providing the impetus for a very lively and well-attended series of programs. Special events such as "Frog Week" encouraged regular and enthusiastic attendance.

Collection Management
Collection development has been restricted due to lack of funds. However, a number of gifts have continued to be made under the Tax Incentives for the Arts Program.

A major research project was undertaken by the Curator of Geology into "Fossil Sharks from Queensland, Australia — their palaeogeographical and palaeoenvironmental significance". The field work in the Eromanga Basin was funded by a grant from the National Geographic Society.

Major publications include "A Directory of Tasmanian Photographers 1840–1940", a survey of photographers working in Tasmania during that period.

Staff and Volunteers
The volunteer guide training and tour programme developed for the Arthur Boyd Retrospective, has continued under the management of Jan Peacock. In April Dr Christa Johannes retired as Education Officer but she continues to contribute to the TMAG as a volunteer guide. Carolyn Parsons has been appointed as Visitor Services Co-ordinator, a position which incorporates Education Officer and public relations functions.

The employment of some 12 young people under the Jobskills training program has helped relieve some of the pressure on the TMAG's staff, which is at a chronically low level. The staffing establishments for the TMAG of 36.5 FTE and the QVMAG of 44 FTE are clearly inadequate when compared with the Museum and Art Gallery of the Northern Territory, establishment of 102 FTE staff.

The appointment of Andrew Rozefelds as Phanerogamic Botanist has given new impetus to the Herbarium program by rebuilding the full complement of curatorial skills.

The Trustees commend the special efforts made by the staff of the TMAG this year. They have maintained a full program of exhibitions and other events, obtained substantial grants and sponsorship to support core business activities and continued their research whilst managing the refurbishment of and move to the Custom House.

Royal Tasmanian Botanical Gardens

Mr J.E. Tomlinson AO was elected to serve on the board of Trustees. He arranged for the Society to receive the following report on the year's activities from Mr Jim Cane:

A very important event was the launch of the new Logo of the Gardens by the Hon. Ray Groom, Premier of

Tasmania, and Mrs Groom during the Tulip Festival on 24 September. At the same event, the Director, Dr David Bedford, launched the Gardens Objective and Mission Statement. This Statement reads "To further sustainable development by increasing knowledge, awareness and understanding about plants, their economic, social and ecological value; by programmes of conservation; by caring for and stewarding the Gardens, having regard to their value as a primary scientific, educational, tourism and passive recreation resource."

A new bed for small bulb species and varieties was constructed near the Conservatory, the bulbs supplied by Rod Barwick, and a new collection of water lily varieties placed in the Lily Pond. More trees were entered on the National Trust "Significant Tree Register". Regrettably, severe infestations of two root rot diseases, *Armillaria luteobubalina* and *Phytophthora cinnamomi*, were detected, one of the affected trees being a 150-year-old cork tree. Treatment included major excavation. The State Government provided supplementary funding to help control the diseases. New drainage and reconstruction in the A.P. May Tasmanian Native Plant Garden was designed to overcome *Phytopthora* infestation. The severity of the outbreak in the Gardens is being gauged by mapping and testing.

The RTBG joined the University of Tasmania to form a Southern Hemisphere Conifer Research and Conservation Centre. Planting commenced in a newly completed Epacridaceae garden. The Gardens advised Temco and Comalco on wetland conservation and revegetation at Bell Bay. Co-operative programmes with Forestry and Parks and Wildlife were concerned with threatened species and species recovery and the Gardens continued collection of native and endemic species statewide. Further, the Gardens has a contract with the Department of Transport and Works dealing with the roadside rescue of rare and threatened species.

Important negotiations have begun with the Hobart City Council on the possibility of using recycled sewage water for irrigation purposes.

Participation In the Jobskill programme has included projects such as the removal of weeds and non-native plants from the Gardens land on the Derwent foreshore and revegetation. Other projects were in the areas of education and interpretation, nursery practice, horticulture and horticultural therapy among others.

Staff have attended many courses in arboriculture, occupational health and safety, horticulture in the TAFE system and in-house courses with DELM.

A grant was received from Department of Industrial Relations to develop and emplace an Enterprise agreement for staff which will include strategic planning and development of business plans. Two members of staff, Mr Jim Cane, Horticultural Operations Manager, and Dr Leonie Scriven, newly-appointed Manager of Research and Documentation, have gained fellowships; Mr Cane a Churchill Fellowship to attend an International Diploma Course in Botanic Gardens Management at Kew, UK, in July/August 1996, Dr Scriven a Savings and Loans Credit Union Fellowship to study Botanic Gardens in Melbourne, Canberra and Sydney. Dr Bedford and Andrew Smith attended the International Botanic Gardens Conservation Congress in Perth in September.

The Gardens or Gardens staff received grants in excess of $10 000 from the Federal Department of Primary Industry and Fisheries (installation of four heritage-style, solar-powered lights), the Friends of the Gardens (development of new signage and entrance information displays), Australian Antarctic Foundation (to develop a sub-Antarctic plant display), and for Dr Scriven, an Australian Research Council Small Grant (investigate fossil and living *Nothofagus* leaf anatomy as a bioindicator of climate). Smaller grants were received from Computerland, the Garden History Society, DJ Motors (2) and the Australian Open Garden Scheme.

Major events during the year included:
In the cultural area — Theatre in the Gardens with performances of *Wind in the Willows*; *Midsummer Nights Dream* and *The Lizard of Oz*; Music in the Gardens on Mothers Day and Fathers Day.
Education — Home Gardeners School of Landscaping; Winter Garden School; and others.
Tulip Festival — attendance 12 000.
Displays — were arranged for Garden Week Hobart, and Launceston Garden Festival.

Facilities for visitors were improved by the provision for the first time of a Metro bus service. A feasibility study has been commissioned on a new Visitors Information Centre.

The Gardens and the programmes associated with them attracted almost 312 000 people in 1995.

Acknowledgements

The Council is grateful for help generously given by many individuals and organisations. The lecturers, the Government of Tasmania, the University of Tasmania, Arts Tasmania, the Tasmanian Museum and Art Gallery and the Queen Victoria Museum and Art Gallery are particularly thanked for their support and cooperation.

Attention is drawn to the help received from Dobson Mitchell and Allport and Perpetual Trustees in connection with the establishment of the Foundation, from the proprietors of Moorilla Winery, the Ashgrove Cheese Factory and from the Hollybank Forest Advisory Committee during visits by members to facilities under their control. Council thanks these bodies for their help and hospitality.

Penny McCartney
Vice-President
1 February, 1996

M.R. Banks
Hon. Secretary

ROYAL SOCIETY OF TASMANIA

Balance Sheet as at 31 December 1995

1994		*1995*
79 260.58	Accumulated funds	60 051.00
21 333.31	Trust Funds/bequests etc	0.00
–	Foundation Funds	23 134.10
7 004.77	Life Membership Fund	7 004.77
$107 598.66		$90 190.17
Represented by:		
40 458.29	General account	40 134.07
5 081.59	*Papers and Proceedings* acct	0.00
2 701.78	Memorial funds	0.00
860.00	Mortgage Loan	0.00
7 000.00	Interest bearing deposit	0.00
0.00	Foundation Trust Fund Perpetual Trust	23 134.10
15 000.00	Library (at valuation for insurance)	15 000.00
30 897.00	Publications (estimated realisable value)	5 000.00
5 600.00	Medals (at selling price)	5 600.00
0.00	New assets	1 322.00
$107 598.66		$90 190.17

Notes to accompany Balance Sheet for 1995

The Balance Sheet for 1995 represents a revision and clarification of the Society's funds.

All investment, Trust and Bequest items have been organised and accumulated by Perpetual Trustees and are now managed as the Royal Society Foundation Trust Fund. This action has greatly simplified the accounts

Publications have been largely written off in accord with Council decisions concerning older stock. This action was planned for early 1995 but was delayed pending special sales to members to assess interest and recover some value. The new estimated value covers the limited stocks (mainly recent volumes) now retained.

Medals will be reviewed in 1996. From this year new asset items will also be included.

I have been advised by the Auditor that it is impractical to properly assess and value older items which have never been declared or tabulated and that the Society should accept the present report as a convenient starting point.

D.E. Leaman
Hon. Treasurer

Royal Society Foundation
Statement for Year ending 31 December 1995

The Foundation was approved by the membership and Council in 1995, and officially opened in November 1995. The Royal Society Foundation Trust Fund replaces all previous Trust and Memorial Funds — which have now been accumulated into it. Complete details of interest/charges and a full balance sheet will be supplied after the first full year of operation.

Funds held by Perpetual Trustees (as managers) (current statement)	23 134.10
Funds currently held in Society general account (pending transfer in 1996)	2605.00
Total funds of Foundation	25 739.10

Statement of Receipts and Payments
Year ending 31 December 1995

Balance - 1 January 1995 (as audited for 1994)			$40 458.29
Add Receipts			
Subscriptions		13 618.00	
Sundry cash		24.50	
Publications regular sales	6806.44		
rare book sale	3720.00	10 526.44	
Donations to Society	69.80		
to Foundation	2605.00	2674.80	
Interest		963.61	
Government grant		5000.00	
Christmas payments/funds			1010.00
Sundries sale of chairs	440.00		
room hire	471.60		
old WHA payment	355.00	1266.60	
			add 35 083.95
Deduct payments			
Subscriptions		3049.14	
Print and stationery		855.07	
Postage		1906.53	
Meetings Attendants fees	990.00		
1994, 1995 Xmas	4178.20		
Sundries	415.00		
Sound system	1322.00	6905.20	
Bank charges		61.91	
Publication costs		6571.37	
Post Box		190.00	
Telephone		155.28	
Northern Branch		1650.00	
Secretarial services		3200.40	
Cataloguing		14.52	
Administration/insurances			593.90
Chair restoration costs		80.00	
Presidential gift/honour board		784.00	
Legal advice re Foundation		205.00	
Bad debt (cheque)		35.00	
Foundation advertising/promotion		1631.67	27 888.99
Special interest payment transfer to Perpetual Trustees			5960.43
Uncashed payments from 1994 carried			1558.75
			less 35408.17
Balance — 31 December 1994			$40 134.07
Reconciliation (payments not cashed)		609.95	
(Balance in general account at bank		40 744.02)	

Accumulation Account
for Period 1 January–31 December 1995

	Balance at 1 January 1995	79 260.58
Cash items		
Add	Increases at bank	7294.96
Less	Interest funds transferred to Foundation account	1929.24
	Subtotal at 31 Dec 1995	84 626.30
Asset items		
Less	Write-off of old publications (in accord with Council directives)	25 897.00
Add	New assets as per statement of payments	1322.00
	New total for 1995	60 051.30

BATS OF COASTAL SOUTHWESTERN TASMANIA

by Martin Schulz and Kris Kristensen

(with two tables and one text-figure)

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A survey of bats was undertaken in coastal southwestern Tasmania from Bond Bay north to Pilot Bay at Macquarie Harbour entrance. Survey sites were located within wet scrub and buttongrass moor vegetation communities, predominantly along watercourses or on ecotones with beaches or marsupial lawns. Of the eight species of bats so far known from Tasmania, only *Falsistrellus tasmaniensis* was not recorded in the present survey. A total of 53 individuals were captured in 111 mistnet hours from 22 survey sites sampled, including five species not previously recorded from southwestern Tasmania — *Nyctophilus timoriensis*, *Chalinolobus gouldii*, *C. morio*, *Vespadelus darlingtoni* and *V. vulturnus*. The most widespread and frequently trapped species was *N. geoffroyi*. Species captured infrequently were *V. regulus* and *N. timoriensis* (two sites) and *V. vulturnus* (one site).
Key Words: bats, mistnet, southwestern Tasmania.

INTRODUCTION

Little survey work has been conducted on bats in southwestern Tasmania, with the majority of survey effort confined to the vicinity of Melaleuca airstrip adjacent to Melaleuca Inlet (e.g. Schulz & Menkhorst cited in Taylor *et al.* 1987, Taylor & Comfort 1993, Department of Parks, Wildlife & Heritage records). This paper reports the results of a survey of bats of coastal southwestern Tasmania, from Bond Bay north to Macquarie Heads, which was conducted during February and early March 1993. Prior to the present survey, only three of the eight recognised bat species occurring in Tasmania had been recorded in the southwestern region — the lesser long-eared bat *Nyctophilus geoffroyi*, King River bat *Vespadelus regulus* and the Tasmanian pipistrelle *Falsistrellus tasmaniensis* (Taylor *et al.* 1987, Rounsevell *et al.* 1991, Watts 1993); the last was not found in the present study.

METHODS

The survey of bats or coastal southwestern Tasmania was undertaken as part of a general fauna survey conducted while traversing the coast on foot from Bond Bay north to Macquarie Heads between 9 February and 11 March 1993 (Schulz & Kristensen 1993a, b, Kristensen and Schulz 1994).

Twenty-two survey sites were sampled (fig. 1), from Bond Bay in the south to Pilot Bay at Macquarie Harbour entrance in the north. All sites were sampled on only a single night. Survey sites were either deliberately selected as being suitable for trapping bats, due to the presence of suspected "flyways" along creeks (Taylor & O'Neill 1985), or were set at sites where we were forced to camp for the night.

Survey sites occurred within two principal vegetation communities which, following the classification of Kirkpatrick & Dickinson (1984), were wet scrub (91%),and buttongrass moor (9%). The majority of sites were located over watercourses up to 150 m from the shoreline within wet scrub (50%) or in ecotones with beaches (23%) or marsupial lawns (9%) immediately adjacent to the shoreline (table 1). All sites were located at altitudes of less than 10 m above sea level.

Three techniques were employed to survey the bat fauna of coastal southwestern Tasmania.

(1) *Monofilament mistnetting.* At all 22 sites, between one and four monofilament mistnets of three lengths, 5.5 m, 12.9 m and 18.5 m, were set as single nets angled across watercourses or gaps in dense vegetation. In more open areas, double and triple nets were set in Y-shaped and Z-shaped patterns, as described in Helman & Churchill (1986). Nets were set for a minimum period of one hour after dusk. Taylor & O'Neill (1988) found that bats in all habitats sampled in Tasmania

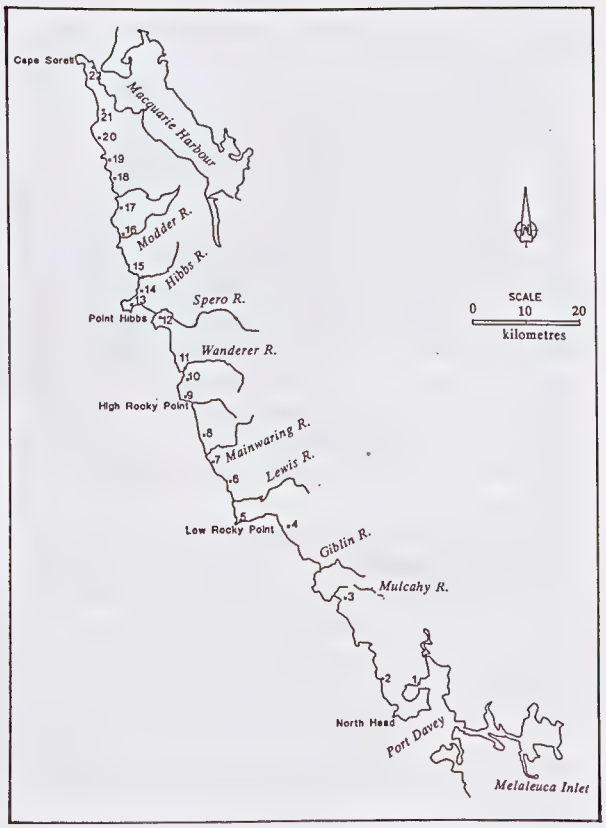

FIG. 1 — Survey sites for bat survey of coastal southwestern Tasmania. Numbers correspond with listing in table 1.

TABLE 1
Survey sites, dates of field work, broad vegetation types, trapping effort and numbers of species of bats recorded

Site no.	Locality	Grid ref.	Date	Habitat*	Trap effort†	Species recorded
1	Bond Bay beach	43°15'S, 145°54'E	9.2.93	Wet scrub/beach	4.5	1
2	Paradise Lagoon	43°15'S, 145°49'E	10.2.93	Wet scrub/creek	6.0	0
3	Alec Rivulet, Mulcahy Bay	43°07'S, 145°43'E	12.2.93	Wet scrub/creek	1.0	0
4	Unmarrah Creek mouth	43°01'S, 145°38'E	14.2.93	Wet scrub/marsupial lawn	2.25	1
5	Low Rocky Point	42°59'S, 145°29'E	16.2.93	Buttongrass moor	1.25	0
6	Sassy Creek mouth	42°55'S, 145°29'E	17.2.93	Wet scrub/creek	12.0	4
7	Stinky Creek mouth	42°53'S, 145°27'E	18.2.93	Wet scrub/marsupial lawn	10.0	4
8	Reuben Creek	42°49'S, 145°25'E	19.2.93	Wet scrub/creek	4.0	1
9	Minder Cove	42°46'S, 145°23'E	20.2.93	Wet scrub/beach	4.0	1
10	South of Hartwell Cove	42°44'S, 145°23'E	21.2.93	Wet scrub/beach	2.0	1
11	Wanderer River mouth	42°43'S, 145°23'E	22.2.93	Wet scrub/beach	4.0	1
12	Spero River mouth	42°38'S, 145°20'E	27.2.93	Wet scrub/river	9.0	2
13	Whitehorses Beach	42°37'S, 145°18'E	28.2.93	Buttongrass moor/beach	4.0	1
14	Evans Creek mouth	42°36'S, 145°18'E	1.3.93	Wet scrub/creek	4.0	3
15	Hibbs Lagoon mouth	42°34'S, 145°18'E	2.3.93	Wet scrub/creek	6.0	0
16	Modder River mouth	42°30'S, 145°15'E	3.3.93	Wet scrub/river	5.0	2
17	Birthday Creek mouth	42°27'S, 145°15'E	4.3.93	Wet scrub/creek	3.0	2
18	North of Birthday Bay	42°25'S, 145°14'E	5.3.93	Wet scrub/creek	7.5	0
19	South of Gorge Point	42°22'S, 145°13'E	6.3.93	Wet scrub	5.0	0
20	South of Sloop Point	42°20'S, 145°12'E	7.3.93	Wet scrub	7.5	0
21	South of The Grandfathers	42°16'S, 145°13'E	8.3.93	Wet scrub/creek	4.0	1
22	Pilot Bay	42°12'S, 145°12'E	10.3.93	Wet scrub	5.0	3

* Broad vegetation types (after Kirkpatrick & Dickinson 1984)/position of mistnet (over watercourses or marsupial lawn/beach ecotones).
† Trap effort measured in mistnet hours.

concentrated their foraging activities to an initial period of three hours after dark. In order to obtain a measure of relative net success for each species, the number of mistnet hours sampled at a particular site represented the number of nets set, irrespective of net length for the sample period. Mistnets were constantly monitored to retrieve bats before they chewed their way through the net and escaped.

(2) *Triplining.* This technique was only used at a single site in buttongrass moor at Low Rocky Point. Fine nylon fishing line (0.25 mm diameter) was stretched tightly about 20–30 mm above a still water surface. Bats coming in to drink hit such lines, and some are flipped into the water, forcing them to swim to the bank where they can be caught (Helman & Churchill 1986). As with mistnets, triplining requires a person to be constantly monitoring the lines in order to stop bats from reaching the bank and escaping.

(3) *Search of sea caves.* All sea caves, overhangs along watercourses and crevices in rock faces encountered were searched for roosting bats.

Mistnetting was conducted on 22 nights of the 32-day survey. Climatic conditions ranged from calm weather to wind speeds of less than 20 knots, no rain to showers and squalls, and no moon to full moon. On the remaining nine nights, survey work was not conducted, due to adverse climatic conditions with wind speeds of over 20 knots and/or constant rain, or to forced camp sites in situations where it was not feasible to erect nets, because of the nature of the terrain, the lateness of arrival or the physical condition of the authors.

RESULTS

Seven of the eight species of bats known from Tasmania were recorded in this survey. In a total of 111 mistnet hours at 22 survey sites, 53 individuals (all species combined) or 0.48 bats/mistnet hour were captured. The greatest number of species recorded from a single site was four species (two occasions) and no bats were recorded from seven sites (table 1). Trapping results for bats recorded during the survey are given in table 2. No bats were caught using the triplining technique.

Nyctophilus geoffroyi was the most commonly trapped (20 individuals) and widespread species (nine sites), with a capture rate of 1.8 individuals/ten mistnet hours. Other species recorded in more than five survey sites were *Chalinolobus morio* (nine individuals trapped at seven sites) and *C. gouldii* (11 individuals trapped at four sites). One species, *Vespadelus vulturnus,* was trapped as a single individual from one site. Two species were recorded from only two survey sites, *N. timoriensis* and *V. regulus.*

All seven species were recorded from wet scrub, while only one, *N. geoffroyi,* was trapped in buttongrass moor. Six species (*C. gouldii, C. morio, N. geoffroyi, N. timoriensis, V. regulus* and *V. darlingtoni*) were captured in mistnets set over watercourses fringed by wet scrub. Four species (*C. gouldii, C. morio, N. geoffroyi* and *V. darlingtoni*) were trapped on the ecotone of wet scrub and shoreline, and four (*C. morio, N. geoffroyi, N. timoriensis* and *V. darlingtoni*) on the ecotone of wet scrub and marsupial lawns immediately adjacent to the shoreline. *V. vulturnus* was only captured in a mistnet angled across a four-wheel drive track behind Pilot Bay at Macquarie Harbour entrance.

No bats were located in sea caves or overhangs along watercourses, although several sea caves which could potentially provide suitable roost sites were located between the Mainwaring River and Endeavour Bay. The only roosting bat encountered was a single *N. geoffroyi* located 4 m above the ground in a tangle of bark and sticks accumulated in the fork of a *Eucalyptus nitida*, north of Christmas Cove (42°42'S, 145°23'E).

DISCUSSION

The seven species recorded in the survey area represent 88% of the known bat species of Tasmania. This compares with 50% found by Taylor *et al.* (1985) in the Upper Henty River region of western Tasmania and 12% found by Green (1979) in the Sumac Forest and Dempster Plains in northwestern Tasmania. All species of bats recorded from the Upper Henty River region and from the Sumac Forest and Dempster Plains were found in the present study area.

Prior to the present survey, only three species of bats had been recorded from southwestern Tasmania (Taylor *et al.* 1987, Rounsevell *et al.* 1991, Taylor & Comfort 1993). The most frequently recorded species was *N. geoffroyi*. This bat was found roosting on occasions in the bushwalkers' huts at Melaleuca (M. Schulz, pers. obs.) and for periods of time in the Willson's house a Melaleuca (P. & B. Willson, pers. comm.). It was also captured in mistnets set around D. King's garden at Melaleuca (M. Schulz & K. Menkhorst, unpubl. rec.). No individuals of this species were caught in harp traps or recorded by an ultrasonic bat detector at Melaleuca and Claytons by Taylor & Comfort (1993). Away from Melaleuca, *N. geoffroyi* has been caught in monofilament mistnets at Schooner Cove, Cox Bight, Louisa Bay and Louisa River (M. Schulz & K. Menkhorst unpubl. rec., Taylor *et al.* 1987).

Two other bat species previously recorded from southwestern Tasmania appear to be restricted in distribution within this region. *V. regulus*, captured only once in the present survey, had been recorded by M. Schulz and K. Menkhorst (cited in Taylor *et al.* 1987) and Taylor & Comfort (1993) at Melaleuca. (The latter authors did not trap this species at the site but obtained a bat recording that "most closely resembled" it.)

The Tasmanian pipistrelle *Falsistrellus tasmaniensis*, previously recorded from the New Harbour area on the south coast (Taylor *et al.* 1987, Rounsevell *et al.* 1991), was not located this time, possibly because all trapping was confined to wet scrub and buttongrass moor vegetation communities rather than taller forest communities.

The present study, together with previous records, has shown that all eight species of bats recorded for Tasmania occur in southwestern Tasmania. Rounsevell *et al.* (1991) suggested that *C. morio, N. geoffroyi V. darlingtoni* and *V. regulus* are probably distributed throughout most of the state while *C. gouldii, F. tasmaniensis, N. timoriensis* and *V. vulturnus* may be limited within the perhumid cold climatic zone (after Gentilli 1972). The present survey showed *C. gouldii* to be widely distributed in this climatic zone and *N. timoriensis* to be patchily distributed; no information was available for *F. tasmaniensis. V. vulturnus*, on the other hand, was only recorded in the humid warm zone (Gentilli 1972) at Macquarie Harbour entrance and may possibly be absent from the perhumid climatic zone of southwestern Tasmania.

Five of the species now recorded (*C. gouldii, C. morio, N. timoriensis, V. darlingtoni* and *V. vulturnus*) had not been located previously in southwestern Tasmania (Taylor *et al.* 1987, Rounsevell *et al.* 1991). The first two were widespread, being recorded at four and seven sites respectively. *V. darlingtoni* was recorded from three sites, *N. timoriensis* from two sites and *V. vulturnus* from a single site (table 2). The location of five additional bat species was attributed to the survey effort undertaken in this study and sampling of areas not previously surveyed. In the most comprehensive survey previously undertaken in the region (Taylor & Comfort 1993) at Melaleuca, a total survey effort of five harp trap nights, two nights of mistnetting and four nights of 45-minute sampling, using a Anabat II (Titley Electronics) bat detector, yielded no bat captures and only two bat passes recorded with the detector. The present survey sampled 22 sites with a total of 111 mistnet hours, averaging 5.1 mistnet hours/site. This effort resulted in recording bats (one species or more) at 68% of sites, with three or more species recorded in 18% of sites sampled.

Bat species diversity is generally considered to be low in western Tasmania (Taylor & O'Neill 1985, Taylor *et al.* 1987, Taylor & Comfort 1993). Taylor *et al.* (1987) attributed this to the cold climatic conditions and high rainfall of the region in comparison with eastern Tasmania. The present survey has demonstrated that bat species diversity overall in coastal southwestern Tasmania is comparable

TABLE 2
Summary of trapping results in the survey of bats in coastal southwestern Tasmania

Species	Total trapped	Vegetation community*		Sites recorded†
		Wet scrub	Buttongrass moor	
Nyctophilus geoffroyi	20	+	+	7,8,10,12,13,14,17,21,22
Chalinolobus gouldii	11	+	–	6,11,14,16
C. morio	9	+	–	1,4,7,12,14,16,22
Vespadelus regulus	5	+	–	6,17
N. timoriensis	4	+	–	6,7
V. darlingtoni	3	+	–	6,7,9
V. vulturnus	1	+	–	22

* After Kirkpatrick & Dickinson (1984).
† Site numbers used are those identified in table 1.

with that of eastern Tasmania. In forested sites in eastern Tasmania, trapping records indicate that it is not uncommon for seven or eight species to occur sympatrically (Taylor *et al.* 1987). During the present survey, in a single night of mistnetting at each of four sites, three or four species were recorded. Since the use of mistnets is generally considered to be less effective than harp traps (e.g. Richards 1992), and all net sites during the present survey were located in scrub rather than forested situations, a survey of coastal forests in western Tasmania deploying harp traps and ultrasonic bat detectors could reveal a similar bat species diversity, with the possible absence of *V. vulturnus*, to that in many forested situations in eastern Tasmania.

The density of bats present in coastal southwestern Tasmania appears to be lower than in eastern Tasmania, although no data was collected to quantify this. Taylor & Comfort (1993), using an Anabat II detector, demonstrated a marked difference in bat passes, with 80 times greater number of passes in dry forest in eastern Tasmania compared with around Melaleuca Inlet. However, the bat fauna present at Melaleuca appears depauperate and is unlikely to be representative of southwestern Tasmania as a whole. For example, in over 50 monofilament mistnet hours in late 1992 and early 1993, M. Schulz and K. Menkhorst (unpubl. rec.) recorded only 12 *N. geoffroyi* and three *V. regulus*. These results are low compared with many sites sampled in a single night during the present survey. At some locations during the survey, such as south of Hartwell Cove and at the Wanderer River mouth, large numbers of bats were observed foraging over the shoreline and adjacent vegetation. Both these sites were close to rainforest and E. *nitida* wet forest vegetation communities (Kirkpatrick & Dickinson 1984). Fishermen reported on some summer nights having large numbers of bats flying around boats anchored close inshore at The Pophole, south of Low Rocky Point (C. Wessing, pers. comm.) where *E. nitida* wet forest immediately flanks the shoreline in this area.

In a total of 544 bats trapped at nine sites in eastern, western and northwestern Tasmania, Taylor *et al.* (1987) found the following relative proportions of each species: *V. regulus* 35%, *C. morio* 20%, *V. darlingtoni* 12%, *V. vulturnus* 11%, *N. geoffroyi* 10%, *F. tasmaniensis* 7%, *N. timoriensis* 3% and *C. gouldii* 2%. In the present survey, the relative proportions of trapped species was: *N. geoffroyi* 38%, *C. gouldii* 21%, *C morio* 17%,*V. regulus* 9%, *N. timoriensis* 8%, *V. darlingtoni* 5% and *V. vulturnus* 2%. Thus, of the three most frequently captured species in southwestern Tasmania, only one (*C. morio*) rated in the top three bat species trapped by Taylor *et al.* (1987). The species recorded least frequently by Taylor *et al.* (1987), *C. gouldii*, was the second most commonly trapped species in the present study, while species of the genus *Vespadelus*, comprising only 16% of all bats caught, accounted for 58% in the earlier survey. The differing results may be due to a combination of factors, including different vegetation communities and climatic zones sampled, and differences in trapping techniques (e.g. harp traps [Taylor] v. mistnets [present study]).

The remoteness of the southwestern region and surveying on foot greatly restricted techniques available for sampling the bat fauna. The harp trap (Tuttle 1974, Tidemano & Woodside 1978), which has been widely and successfully used for capturing all Tasmanian bat species (Taylor *et al.* 1987, O'Neill & Taylor 1989), is a large, bulky, heavy piece of equipment, totally unsuitable for carrying through the dense trackless vegetation of southwestern Tasmania. Deployed around melaleuca Inlet, such traps have met with only limited success (Department of Parks, Wildlife & Heritage records, Taylor & Comfort 1993). For example, Taylor & Comfort (1993) trapped no bats in five harp traps nights around D. King's garden and mine workings in this area. In the present survey, these traps were not used, due to the dense nature of the vegetation, the necessity of restricting the weight of backpacks for the 32-day walking survey and the difficulty of carrying such traps across ten rivers where all gear had to be floated. Techniques were limited to mistnetting and triplining. As a result, the survey depended on mistnetting as the prime technique, although not carrying mistnet poles but using "bush poles" of reasonably straight, dead branches, driftwood or dead sapling trunks.

Mistnets have a number of drawbacks and consequently are rarely used as the prime survey method in general fauna surveys where remoteness and vehicle access is not a problem (e.g. Richards 1992, Schulz & de Oliviera, pers. obs.). Some of the drawbacks of mistnets are listed below.

(1) Mistnets bias against species which are slow flying and have sufficient manoeuvrability to avoid them, or species that have high-frequency echolocation calls that enable them to detect knots and shelf strings in mistnets. These problems were partially overcome by deploying ultrafine monofilament mistnets, less likely to be detected. To maximise the possibility of catching slow-flying manoeuvrable species, such as *Nyctophilus*, nets were set in puzzle formations or slanted across openings, in an effort to trick the bats.

(2) Mistnets have to be constantly monitored, and it is difficult to survey a number of sites concurrently. In the present survey, mistnets were always erected within easy walking distance from the campsite. This was both to conserve torch batteries, of which we had only a limited supply, and to allow for regular checking of nets while undertaking other duties such as erecting the camp, cooking dinner, repairing equipment and writing-up the day's notes. No attempt was made to sample more than one site per night, for the reasons outlined previously and because the authors had been walking all day with heavy backpacks, often over difficult terrain (Kristensen & Schulz 1994) and frequently did not have the energy to constant monitor distant sites.

(3) Monofilament mistnets are generally regarded as expendable survey items, due to their fragile nature (e.g. Helman & Churchill 1986). In the present survey, the nets used became progressively more full of holes, due to wind catching the nets and wrapping them around vegetation, and on occasions flocks of ducks flew into and sometimes through the nets, resulting in gaping holes. By the end of the survey, most nets were more holes than useful net and were difficult to deploy successfully.

Despite the limitations of using mistnets as the primary bat survey technique, the results demonstrated that monofilament mistnets are a useful bat survey tool, where terrain and remoteness restrict other techniques.

Another widely used bat survey tool, the ultrasonic bat detector, was not used in the present survey. Detection of ultrasonic calls requires the careful use of delicate electronic equipment (de Oliviera *et al.* 1994) not resistant to water. It was considered impractical to carry a bat detector, cassette recorder, cassette tapes and a large supply of batteries, and the equipment might well have failed in wet weather or during river crossings and/or accidental submersion of backpacks in the sea. The only localities in coastal south-

western Tasmania where ultrasonic bat detectors have been used are at Melaleuca and Claytons on the southern shore of Bathurst Harbour (Taylor & Comfort 1993). However, in future surveys of western Tasmania, it is recommended that a waterproofed bat detector also be deployed as, at a number of sites, bats were observed lying around but none were caught in the nets.

The absence of bats in sea caves scattered along the coast, particularly in the High Rocky Point area, was not a surprise. No cave-dwelling bats have been reported in Tasmania (Taylor *et al.* 1987, Rounsevell *et al.* 1991, Watts 1993). Hall (1981) indicated that cave-dwelling species are generally less numerous in mainland Australia than forest roosting species and decrease in numbers with increasing latitude.

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HIGH RESOLUTION STABLE ISOTOPE ANALYSIS OF A TASMANIAN SPELEOTHEM

by Jol M. Desmarchelier and Albert Goede

(with eight text-figures)

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High resolution oxygen and carbon isotope analyses of part of a uniform diameter stalagmite from a cave in northern Tasmania have been used to study the climatic transitionfrom stadial to interstadial conditions during the early Last Glacial (109–95 ka). A significant change in oxygen isotope values suggests that temperature warmed rapidly by approximately 2°–3°C between 100 and 97 ka. A decrease in carbon isotope values between 101 and 98 ka indicates that moisture availability was increasing slightly in advance of rising temperature.
Key Words: Speleothem, stable isotope analysis, climatic change, Last Glacial, Tasmania, Australia.

INTRODUCTION

The aim of this study was to produce a high resolution record of the the stable isotope composition ($^{18}O/^{16}O$ and $^{13}C/^{12}C$) of the basal 600 mm of a 1420 mm tall, uniform diameter calcite stalagmite (LT) from Little Trimmer Cave in the Mole Creek karst region, northern Tasmania (146°14'4"E, 41°34'21"S). The site is at an altitude of 460 m (fig. 1). A low resolution study had been done previously (Goede *et al.* 1986) but did not include interpretation of the basal 400 mm because of doubts that deposition had occurred under conditions of isotopic equilibrium. These doubts have been resolved by the present study (Desmarchelier 1994).

Uniform diameter stalagmites, when examined in longitudinal section, consist of a central core where vertical accretion takes place on a subhorizontal surface, producing a sequence of convex upward layers surrounded by a narrow mantle formed by discontinuous deposition on a near-vertical outer surface (Goede 1994). Sampling was done at 5 mm intervals along the centre of the axis, using a dental drill with a 1.6 mm bit. In addition, in order to confirm conditions of isotopic equilibrium, seven samples were drilled from each of eight growth layers (Hendy & Wilson 1968) but, following Talma & Vogel (1992), sampling was restricted to the upper subhorizontal portion of each growth layer. Advances in sensitivity and automation of stable isotope mass spectrometers since the previous study of Goede *et al.* (1986) have enabled us to analyse a large number of samples with a much higher degree of measurement precision, while using much smaller quantities of calcite.

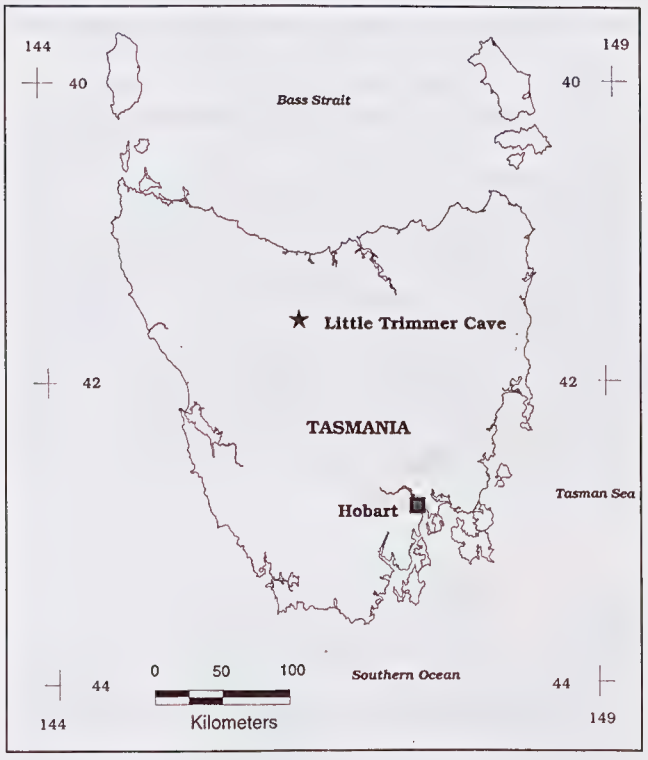

FIG. 1 — Map showing location of Little Trimmer Cave.

GEOCHRONOLOGY

Age determination of the speleothem (LT) is based on alpha particle analysis of seven samples spaced along its length. Four of these fall within the lowest 400 mm (fig. 2). Full analytical details are provided in Goede *et al.* (1986). The time scale used has been determined by linear regression analysis of heights above base against radiometric age estimates of all seven samples ($r = 0.98$). This technique minimises the random error involved in individual age determinations (Goede & Harmon 1983). The regression line indicates a growth rate of approximately 43 mm/ka. Samples at 5 mm intervals represent time intervals of approximately 116 years.

NATURE OF STABLE ISOTOPES

Measurement of variations in the isotopic ratios of $^{18}O/^{16}O$ and $^{13}C/^{12}C$ allows investigation of aspects of environmental conditions. Measurements are expressed as per mil (‰) using the delta (δ) notation relative to the PDB (Peedee Belemnite) standard. The following subscripts are used throughout the text: w – water, c – calcite, p – precipitation and sw – seawater.

$^{18}O/^{16}O$ ratios can be used as indicators of palaeotemperatures provided that certain criteria are met (Hendy 1971, Talma & Vogel 1992). They are:

(1) the carbonate precipitate must have formed in isotopic equilibrium with the dripwater;
(2 the oxygen isotope content of the drip water must be estimated;
(3) no diagenetic alteration of the calcite must have occurred;
(4) the deposit must be datable.

Conditions conducive to isotopic equilibrium are near-constant temperature conditions, humidity close to 100%, and little or no air movement. Such conditions are most likely to be found well away from cave entrances. Deposition of calcium carbonate under isotopic equilibrium conditions will occur only where there is a continuous supply of carbonate-saturated seepage water with a partial pressure of CO_2 greater than that of the cave atmosphere.

Hendy & Wilson (1968) suggested the following tests to confirm the existence of isotopic equilibrium.
(1) Paired measurements of $\delta^{18}O$ and $\delta^{13}C$ taken from the centre of the core along the vertical axis should show an absence of strong positive correlation.
(2) Paired measurements of $\delta^{18}O$ and $\delta^{13}C$ taken from a sequence of at least seven samples along an individual growth layer from the centre of the core outwards should not show a trend towards isotopically heavier values. This test should be done for a number of growth layers.

Harmon *et al.*(1978) have proposed that the variations in oxygen isotope values in speleothems deposited under conditions of isotopic equilibrium are controlled by the three major factors noted below.
(1) Changes occur in the temperature of the depositional environment of the cave. The cave temperature usually approximates to the mean annual surface temperature and will respond to any fluctuations in the latter if climatic conditions change.
(2) Changes in the isotopic composition of seawater occur due to the accumulation of ^{18}O depleted glacial ice on land. They affect the isotopic composition of precipitation by a similar amount.
(3) Changes in the isotopic composition of precipitation are also caused by temperature and humidity changes at sites of evaporation and precipitation, as well as possible changes in the geographical location of moisture source areas.

Goede *et al.* (1986) discussed these factors, noting that factors (1) and (2) cause secondary calcite deposited during cold periods to become enriched in ^{18}O, whereas factor (3) has the opposite effect. Harmon *et al.*(1978) noted that the majority of stalagmites examined by them showed a negative relationship between $\delta^{18}O$ values of calcite and palaeotemperatures. In contrast, stalagmites from Vancouver Island, Norway and Tasmania, all areas subject to a temperate maritime west coast climate, show a positive relationship between $\delta^{18}O$ values of calcite and palaeotemperatures (Gascoyne *et al.* 1980, 1981, Goede *et al.*1986, 1990, Lauritzen *et al.*1990). This indicates that, in these areas, factor (3) is dominant in determining the isotopic ratio of speleothem calcite.

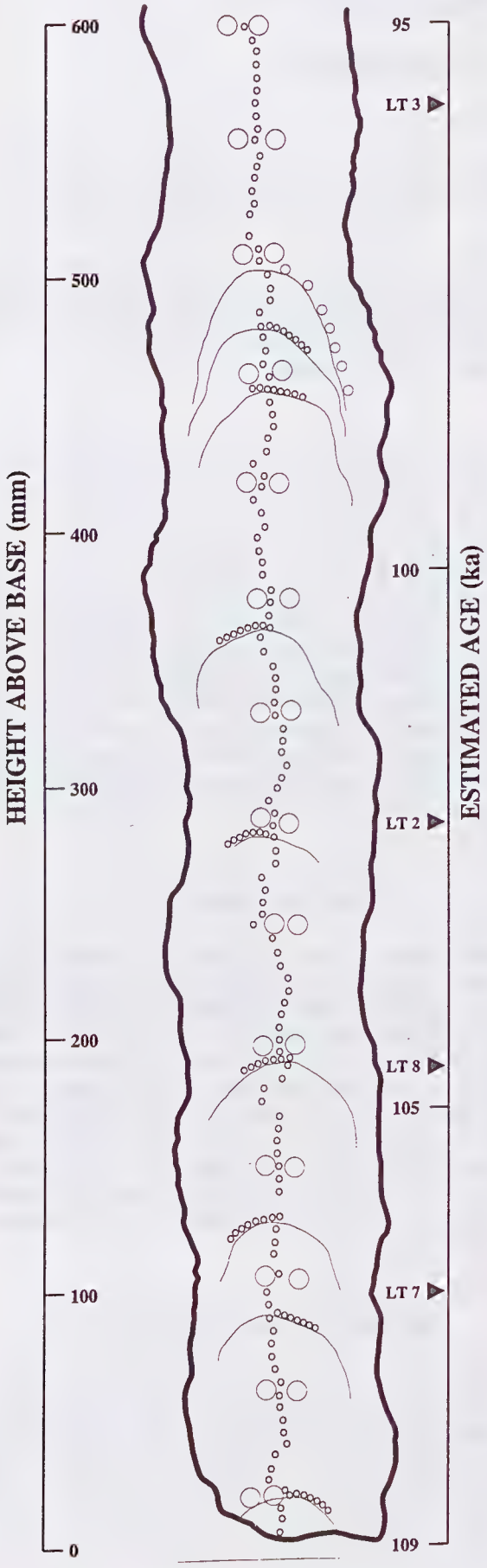

FIG. 2 — Longitudinal section of basal 600 mm of LT stalagmite examined in this study. Median positions of uranium series dates are indicated along the estimated age scale. Concave upward lines represent prominent growth horizons. Large and medium-size circles indicate sampling by Goede et al. *(1986). Small circles indicate high resolution sampling for this study. Sets of samples were taken along growth lines to establish deposition under conditions of isotopic equilibrium.*

Seasonal variation in the isotopic composition of precipitation will not affect seepage waters because soil water is homogenised, causing cave drip water to maintain a near-constant isotopic composition. Goede & Hitchman (1984) and Goede *et al.* (1986, 1990) have shown that, in Tasmania, the isotopic composition at present is best related to the weighted mean value of winter precipitation. This implies that summer precipitation in Tasmania does not contribute significantly to the supply of seepage water. Therefore, the $\delta^{18}O$ values of contemporary Tasmanian speleothems reflect predominantly changes in winter temperatures rather than mean annual temperatures (Goede 1994). This may not always have been true in the past under conditions of wetter and cooler summers.

Variations in $\delta^{13}C$ values in speleothems, unlike $\delta^{18}O$ values, are not related to palaeotemperature. Values are either unrelated or only weakly correlated with the oxygen isotope values. Secular variations in carbon isotope values indicate that they contain palaeoenvironmental information but, until recently, interpretation has been contentious. In recent years, research relevant to this problem has been done not only on speleothems (Brooke *et al.* 1990, Dorale *et al.* 1992, Talma & Vogel 1992) but has also included studies of soil carbonates (Cerling *et al.*1989, Quade & Cerling 1990, Quade, Cerling & Bowman 1989a, b) as well as sub-aqueous wall crust in a karst spring (Coplen *et al.*1994).

The relevant literature is discussed by Goede *et al.* (in press), who conclude that, in temperate environments, changes in $\delta^{13}C$ over time reflect predominantly temporal changes in plant activity, with a minor influence due to natural changes in the isotopic composition of CO_2, at least until the beginning of the industrial revolution (Baskaran & Krishnamurthy 1993, Marino *et al.* 1992). Carbon isotope values are also affected slightly by the composition of the limestone, but this effect is assumed to remain constant during the growth period of a stalagmite. In cool temperate climates, such as are found in Tasmania, plant activity is likely to be controlled by temporal variations in summer insolation and moisture availability.

TESTS FOR ISOTOPIC EQUILIBRIUM

The first test suggested by Hendy & Wilson (1968) involves the degree of positive correlation between $\delta^{18}O$ and $\delta^{13}C$ values of samples taken along the longitudinal axis. A weak but statistically significant negative correlation was found ($r = -0.40$, $n = 119$, $p < 0.001$), confirming deposition under conditions of isotopic equilibrium (fig. 3).

The second test involves examination of sets of seven samples from each of eight growth layers. The position of the samples is illustrated in figure 2. These sets show no significant correlation beween paired $\delta^{18}O$ and $\delta^{13}C$ values, with one exception where the changes are relatively small. Overall the evidence is strongly in favour of deposition under isotopic equilibrium conditions.

PREVIOUS ANALYSIS

The stalagmite was analysed previously by Goede *et al.* (1986) who used a 5 mm masonry drill to sample at intervals of 45 mm. Three growth layers were also sampled to establish deposition under equilibrium conditions. The basal

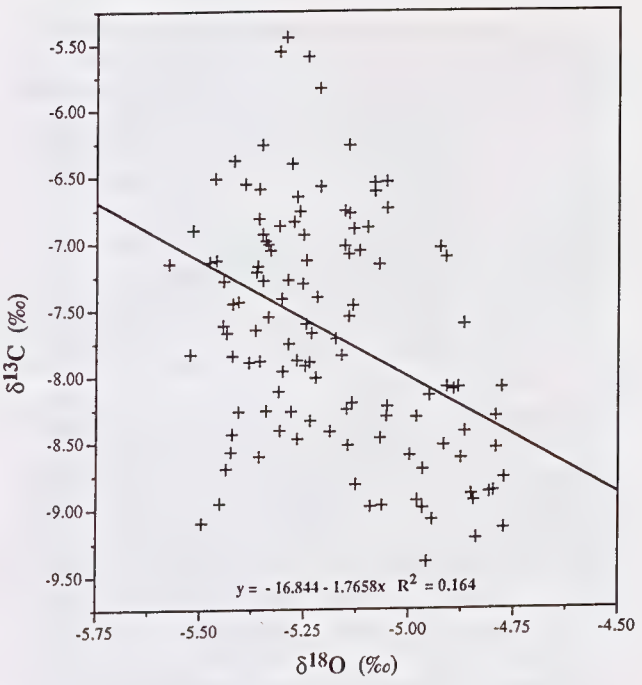

FIG. 3 — Scattergram of 119 $\delta^{18}O$ and $\delta^{13}C$ values of samples taken from the long axis of the LT stalagmite. The regression line is shown.

400 mm was not interpreted as a palaeotemperature record, because of doubts about equilibrium deposition. The results of isotopic analyses done in the previous study are given in figure 4. The present-day isotopic composition of speleothem material was determined by multiple analyses of calcite removed from two plastic funnels used to collect dripwater during 1979. The values obtained were $\delta^{18}O = -3.75$ and $\delta^{13}C = -12.21$‰ PDB.

In an earlier paper dealing with the LT stalagmite, palaeotemperature estimates were obtained by measuring δD_w values of fluid inclusions (Goede *et al.* 1986). The relationship between δD_p and $\delta^{18}O_p$ established by monthly sampling for one year near the cave entrance was used to estimate corresponding values of $\delta^{18}O_w$ at the time of deposition of the stalagmite. These values, in turn, were used to calculate palaeotemperatures. The problem with this approach is that it does not give a unique outcome, since the intercept

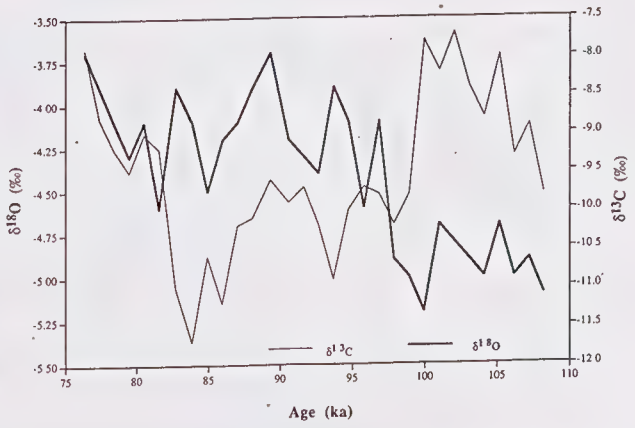

FIG. 4 — Temporal variations in the values of $\delta^{18}O$ and $\delta^{13}C$ obtained by interval sampling of the whole of the Little Trimmer stalagmite in an earlier study (Goede et al. *1986).*

in the relationship between δD_w and $\delta^{18}O_w$, known as the deuterium excess (d_o), is known to have varied over time. In Antarctica, values of d_o have been found to range from 8.3 to 4 over the last glacial–interglacial hemicycle (Jouzel *et al.* 1982). In Tasmania the deuterium excess is unlikely to have remained constant over time, but the amount of variation is not known.

A different approach, first suggested by Gascoyne *et al.* (1980, 1981), is used here. It is particularly appropriate for areas where the oxygen isotope composition of calcite has a positive relationship with temperature ($d\delta^{18}O_c/dT > 0$). It relies on the supposition that the value of $\delta^{18}O_c$ changes in response to three factors:

(1) Changes in cave temperature; at 10°C, the fractionation effect for $\delta^{18}O_c = -0.24‰/°C$ (Epstein *et al.* 1951).

(2) Changes in isotopic composition of precipitation due to changes in the isotopic composition of seawater resulting from variations in the amount of glacial ice on land. Shackleton & Opdyke (1973) estimated that, under full glacial conditions, the value for seawater was 1.20‰ higher than at present. To calculate the effect for a 1°C change in temperature requires an estimate of the amount of temperature lowering in the area during the last glacial maximum. Hannan (1989) used the extent of glacial ice in the Mersey Valley, close to the cave site, to estimate a lowering of mean annual temperature of 6.2°C. This suggests a change in the oxygen isotope composition of –0.2‰ for a 1°C rise in temperature.

(3) In some areas, there is a strong positive relationship between the oxygen isotope composition of precipitation and temperature. Gascoyne *et al.* (1980) suggested that this is due to a change in temperature gradient between the site of evaporation and the site of precipitation. Recent work suggests that the reasons are more complex (Grootes 1993, Rozanski *et al.* 1993). The magnitude of this factor has been determined as 0.7‰/°C for oceanic precipitation sites (Dansgaard 1964, Lauritzen *et al.* 1990).

Gascoyne *et al.* (1980, 1981) summarised the relationship as follows:

$$\Delta\delta^{18}O_c = d\Delta_{c-w}/dT + \Delta\delta^{18}O_{sw} + (d\delta^{18}O_p/dT)\Delta t \quad (1)$$

For a 1°C lowering in temperature, $\Delta\delta^{18}O_c = -2.6‰$.

Since the present-day oxygen isotope composition of calcite is known, temperature at time T_t can be estimated from the following expression:

$$T_t = 9.5 + (\delta^{18}O_c + 3.75)/0.26 \quad (2)$$

This expression has been used to calculate the palaeotemperature estimates shown in figure 5.

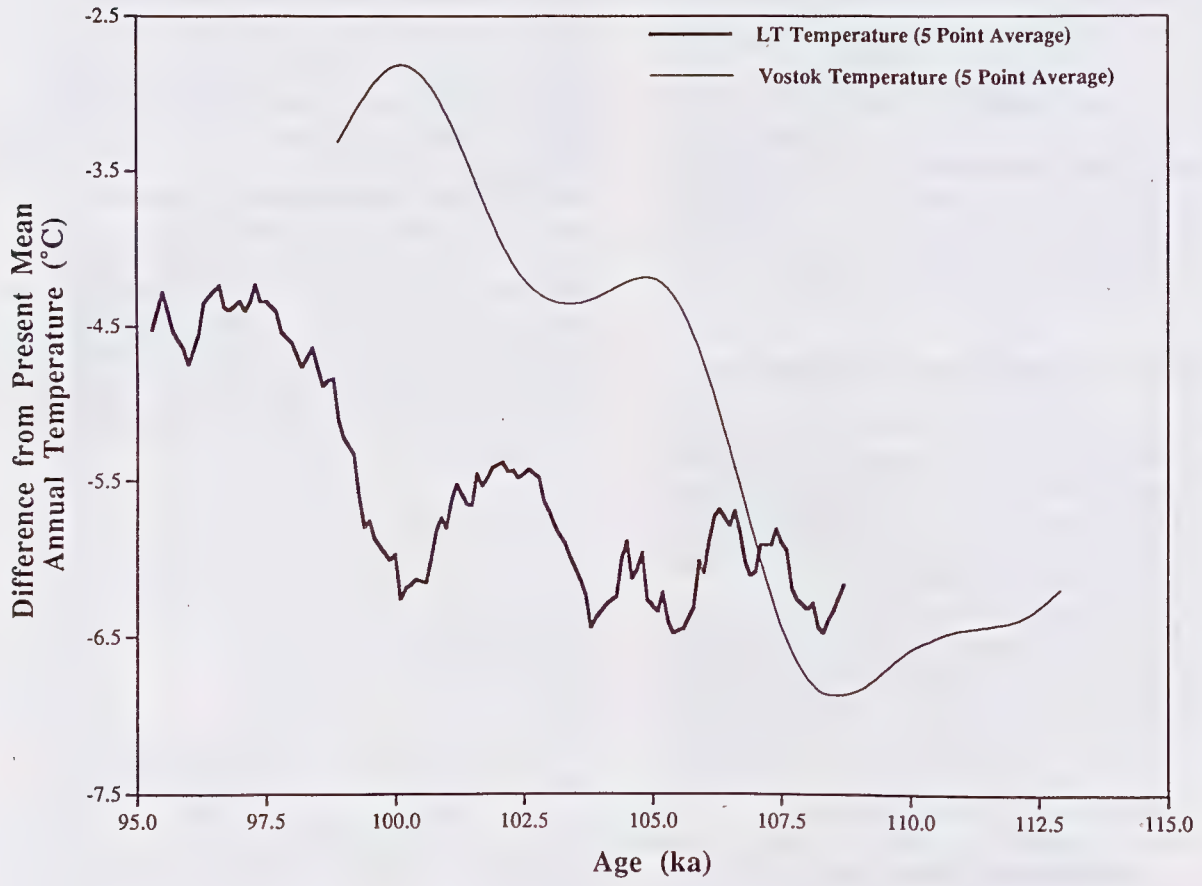

FIG. 5 — Five-year running mean of temperature deviation from the present mean annual temperature of 9.5°C for the LT isotope record compared with the temperature difference record for Vostok where present mean annual temperature is –55.5°C (Lorius et al. *1985).*

DISCUSSION AND RESULTS

Oxygen Isotope Record

The $\delta^{18}O$ values and the five-year running means have been plotted against the estimate age in figure 6. The most significant change occurs between 100 ka and 97 ka, where values rise from –5.4 ‰ to –4.8 ‰ corresponding to a warming of approximately 2°C. In figure 5 departures from the present mean annual temperature of 9.5°C are shown. They have been calculated using equation 2 (above). In the same diagram, the smoothed temperature record from the Vostok ice core is also shown (Jouzel *et al.* 1987).

Figures 5 and 6 suggest that warming, equivalent in time to the transition between marine isotope stages 5d and 5c, occurred in two steps. A similar pattern can also be seen in the Vostok record where a similar stepped temperature rise occurred at approximately the same time. The 3000-year timeshift required to match the two sets of records is easily explained by the limitations of dating. The Vostok record shows a greater temperature rise (4°C) during the transition from 5d to 5c compared with the LT record (2°C). However, following the rise, temperature estimates for the amount of temperature lowering during stage 5c are very similar.

The Vostok record is dominated by a 100 ka glacial–interglacial oscillation with a temperature amplitude of about 6°C (Lorius *et al.* 1985, Jouzel *et al.* 1987). The stages in the Vostok record are identified by capital letters, commencing with A for the Holocene epoch. Vostok stage E is an interstadial, characterised by two well-defined temperature maxima at approximately 100 and 81 ka, as well as some minor oscillations. The earlier maximum appears to match the maximum at 97 ka in the LT record. A slight difference in timing is to be expected, due to limitations in the accuracy of dating in both records. The recent development of uranium series mass spectrometry (TIMS) dating and its successful application to speleothems means that dating precision can be improved substantially (Lundberg & Ford 1994).

Carbon Isotope Record

The $\delta^{13}C$ isotope record is shown in figure 7. There is a fluctuating upward trend from 109 ka until a maximum value of –6.0‰ is reached at 101 ka. Between 101 and 98 ka values fall rapidly to –9.0‰. A slight upward trend follows until the record terminates at 95 ka.

It has been argued that, in cool, temperate climates, carbon isotope variations may be interpreted largely in terms of variations in plant activity, with more negative values indicating higher levels of activity (Goede *et al.* in press). Change in the atmospheric composition of atmospheric CO_2, due to secular variation, can be expected to have made a minor contribution — at least in pre-industrial times.

In the Tasmanian environment, plant activity is seasonal and strongly influenced by available moisture, which can be expected to be at least partly modulated by variations in summer insulation. Some evidence has already been detected that variations in $\delta^{13}C$ in speleothems from Tasmania and eastern Victoria are affected by summer insolation. Goede (1994) published a speleothem record from the Florentine Valley in south central Tasmania, covering a period from 98 to 55 ka. The carbon isotope record shows two prominent peaks of isotopically heavy carbon at approximately 95 and 75 ka and troughs of isotopically light values at 85 and 60 ka. Mid-month insolation data for December at 30°S (Berger & Loutre 1991) show radiation maxima at 95ka (531 W/m^2) and 72 ka (510 W/m^2) and radiation minima at 84 ka (462 W/m^2) and 61 ka (472 W/m^2). A short isotopic record (13.4 to 10.6 ka) from Buchan, eastern Victoria, shows a trough of isotopically light carbon isotope values at 11.2 ka closely following a December insolation minimum at 12.5 ka (474 W/m^2) (Goede *et al.* in press).

Summer insolation minima coincide with winter insolation maxima with a change of similar percentage magnitude. It appears that, in southeastern Australia, conditions for maximum plant productivity coincide with conditions of minimum summer radiation which are also times of minimum seasonal variation. The radiation curve of Berger & Loutre (1991) for the time period examined in this study is of particular interest, because the summer insolation minimum that occurred at 106 ka (mid-month December value of 449 W/m^2) is the lowest of any values calculated for the Late Pleistocene and Holocene.

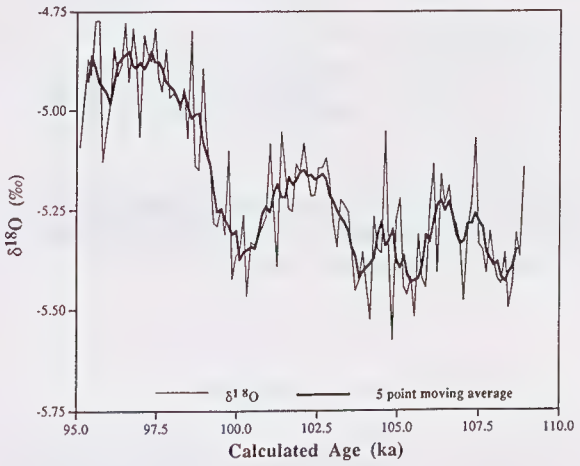

FIG. 6 — Oxygen isotope data plotted against age together with the five-year running mean.

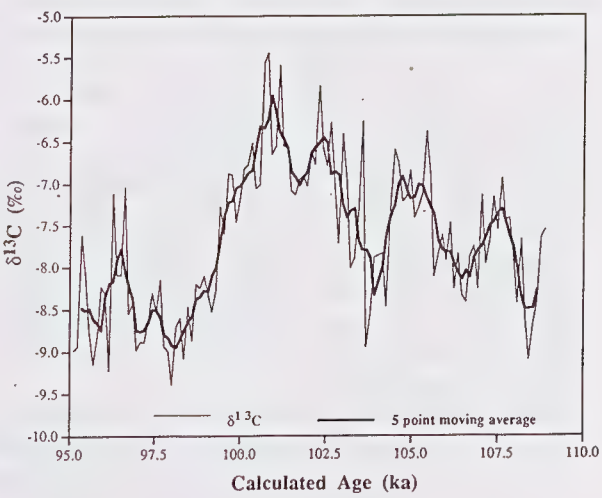

FIG. 7 — Carbon isotope data plotted against age together with the five-year running mean.

In order to test the hypothesis that strongly negative values of $\delta^{13}C$ tend to coincide with summer radiation minima, the $\delta^{13}C$ values for the LT stalagmite have been plotted on the same time scale as the solar radiation curve for 30°S (fig. 8). Agreement between the two curves is poor, but this may be due to the limited accuracy and precision of the early alpha spectrometry dates on which the age scale is based (Goede *et al.* 1986). Until such time as more precise mass spectrometric uranium series dates can be obtained, the hypothesis cannot be adequately tested.

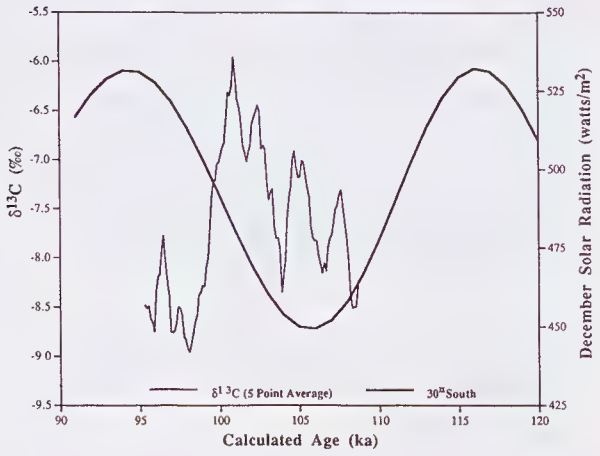

FIG. 8 — Temporal variations in the carbon isotope values compared with fluctuations in solar radiation received for December at 30°S (Berger & Loutre 1991).

CONCLUSIONS

The high resolution isotope record of the basal 600 mm of the LT stalagmite provides a detailed record of local mean winter temperature change for a period corresponding to the transition from marine isotope sub-stage 5d to 5c. It indicates a warming of some 2°C in two phases over a period of some 5000 years, with most of the warming taking place between 100 and 98 ka. The record compares well with that from the Vostok core, if allowance is made for minor discrepancies in age determination. The major difference between the two is that the Vostok record indicates a mean annual temperature rise of 4°C, with most of it taking place during the first warming phase.

The difference between the two records may be due to the likelihood that the LT speleothem reflects predominantly changes in mean winter temperature, while the Vostok record provides a proxy for mean annual temperature. This is supported by the fact that winter insolation at 30°S during this time is declining rapidly, with mid-month insolation for June reaching 199 W/m^2 at 95 ka (Berger & Loutre 1991).

The carbon isotope record at this stage does not support evidence from two other speleothem records from Tasmania and Victoria, that isotopically light carbon isotope values tend to coincide with summer radiation minima. Uranium series MS dating will be required to clarify the relationship. The $\delta^{13}C$ values reached a peak at about 101 ka, indicating a low level of plant activity. They then fell rapidly to a minimum at 98 ka, presumably in response to rising plant activity. The beginning of this trend predated the beginning of a rapid temperature rise at 100 ka. -

ACKNOWLEDGEMENTS

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THE VEGETATION AND FLORA OF THE COAL RIVER NATURE RESERVE

by K.A. Johnson and J.B. Kirkpatrick

(with four tables, four text-figures and an appendix)

JOHNSON, K.A. & KIRKPATRICK, J.B., 1996 (30:vi): The vegetation and flora of the Coal River Nature Reserve. *Pap. Proc. R. Soc. Tasm.* 130(1): 15–23. ISSN 0080–4703. Department of Geography and Environmental Studies, University of Tasmania, Box 252C, GPO, Hobart, Australia 7001.

The Coal River Gorge Nature Reserve occupies most of a sandstone gorge and some adjacent hilltops in a dry part of Tasmania, the vegetation of which is poorly documented. Three dry sclerophyll and two wet sclerophyll plant communities were selected from a TWINSPAN analysis of higher plant species presence–absence data from 200 quadrats. The plant communities formed a continuum from heathy *Eucalyptus tenuiramis*, heathy *E. amygdalina* and grassy/shrubby *E. obliqua* dry sclerophyll communities to *E. obliqua–Pomaderris* and *E. obliqua–Olearia* wet sclerophyll communities. This continuum was related to the catena from the cliff top environments (altitude 350–450 m) to the base of the gorge (approximately 200 m). Soil moisture appeared to be a major variable related to the change in floristics and structure of the vegetation. The reserve, being small and downslope of developed land, has management problems related to nutrient drift, stock grazing and fire.

Key Words: flora, vegetation, dry sclerophyll forest, environmental relationships, conservation, Coal River Gorge, Tasmania.

INTRODUCTION

The characteristics and ecology of the main vegetation types in Tasmania have been well documented (e.g. Jackson 1968, Kirkpatrick 1977, Brown & Podger 1982, Ellis 1985, Kirkpatrick 1991). Studies on plant ecology of particular areas in Tasmania have tended to be concentrated in the west of the state and on the east coast. There are relatively few vegetation descriptions of areas within the dry southeastern–central region of the state (Hogg & Kirkpatrick 1974, Brown & Bayly-Stark 1979, Duncan & Harris 1983). The Coal River Gorge Nature Reserve is situated in the centre of this region. It incorporates a large part of the sandstone gorge of the Coal River 3 km northeast of Colebrook (fig. 1). It is one of the few secure reserves in this part of Tasmania. The documentation of the flora and plant communities of the reserve system is important in determining both gaps in its coverage and appropriate management.

In this paper we document the flora and vegetation of the Coal River Gorge Nature Reserve, analyse relationships between floristically defined communities and environmental conditions, and assess the conservation significance of our results.

THE STUDY AREA

An area of approximately 209 ha on the Coal River was proclaimed a State Reserve in December 1980, under the National Parks and Wildlife Act. Prior to reservation, the area was comprised of freehold land on the western side of the river and crown land, on which grazing leases were held, on the eastern side. From 1978 to 1980 the Lands Department acquired blocks or parts of blocks of this freehold land and terminated grazing leases on crown land which formed integral parts of the gorge. The freehold land acquired by the Lands Department was considered unlikely to be used for agricultural purposes.

The Reserve is located predominantly on sandstones and siltstones of lower Triassic age, except where it has cut into Upper Permian carbonaceous mudstones and siltstones at its southern end (Brighton map sheet 8312N, 1975; Oatlands map sheet 83138, 1975). The gorge has been incised to greater than 200 m along most of its length and is flanked by extremely steep cliffs. The reserve ranges in altitude from approximately 200 m to 450 m.

The mean annual rainfall at Colebrook is about 630 mm. It is relatively evenly distributed throughout the year (fig. 2). The mean daily temperatures in the Reserve are likely to be slightly lower than those given for Hobart Airport, the closest temperature station (fig. 3).

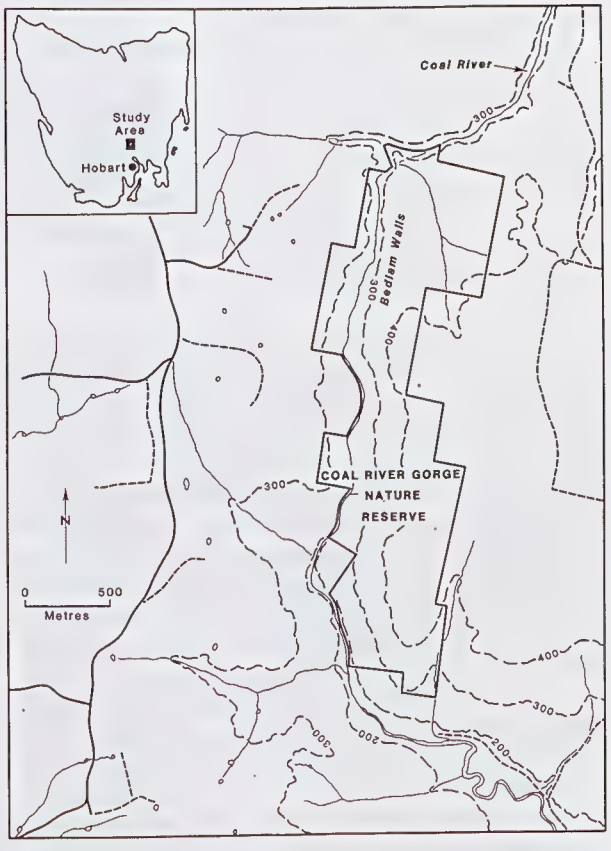

FIG. 1 — Location of the Coal River Gorge Nature Reserve in southeastern Tasmania.

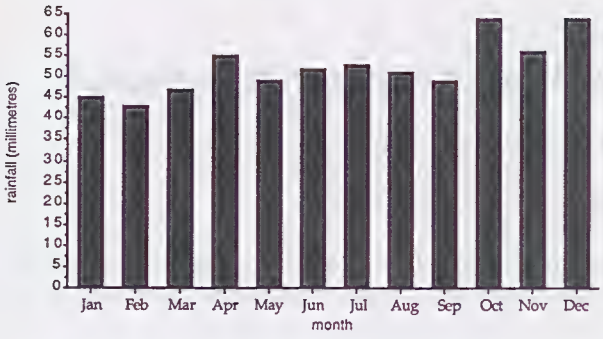

FIG. 2 — Mean monthly precipitation at Colebrook between 1974 and 1991. Source: Bureau of Meteorology, Hobart.

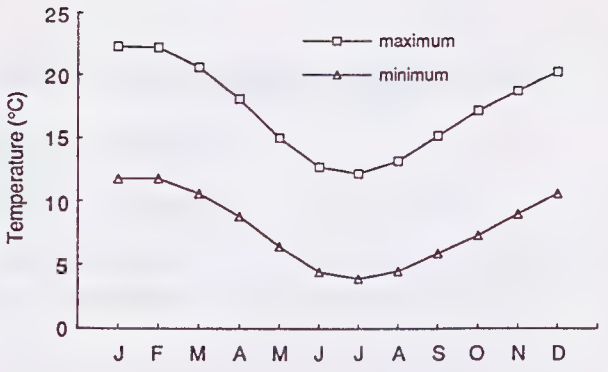

FIG. 3 — Mean daily temperatures from Hobart airport (approximately 50 km south of the Reserve) between 1944 and 1989. Source: Bureau of Meteorology, Hobart.

METHODS

One hundred 5 x 5 m quadrats were located in a stratified random manner. This size was considered to be sufficient to characterise the floristic composition of the vegetation, when combined with Bitterlich Wedge measurements (Mueller-Dombois & Ellenberg 1974) for the taller component. The reserve was divided into four environments: cliff top (48 quadrats); eastern slopes (18 quadrats); western slopes (18 quadrats); base of gorge (16 quadrats). A grid was placed over an aerial photograph of the Reserve and a random numbers table (Kmietowicz & Yannoulis 1976) was used to establish sampling locations. A further 100 quadrats were subjectively located in areas deemed not sufficiently covered by the stratified random location of sites (fig. 4). Most sites were in the reserve, but 11 sites were located on adjacent private property. Vegetation sampling took place from June to August 1992.

A list of the observed vascular plant species was compiled for each quadrat, and the dominant tree and shrub species were recorded. Species names follow Buchanan (1995). The percentage cover of trees, shrubs, ferns, grasses, leaf litter and rocks, and the amount of bare ground at each site were noted, and the average heights of trees, shrubs and ferns were estimated. The Bitterlich Wedge method was used to gain an estimate of basal area of trees at each quadrat. This method includes all plants with stems at eye height.

Within each quadrat the aspect (determined by compass), degree of slope (determined by clinometer), drainage and topographical position (cliff top, cliff, alluvial slopes or valley) were recorded. A soil sample was collected at each site.

The pH of each soil sample was determined by the use of a CSIRO test kit. Each sample was tested three times, and the average of these readings was taken to be the pH of the sample. The percentage weight loss on ignition was determined for each soil sample by the method outlined in Walter (1974). The weight loss on ignition provides an indication of the organic content of the soil.

Communities were selected from a sorted table of floristic quadrat data produced by the polythetic divisive classificatory programme TWINSPAN (Hill 1979). Mean values and standard deviations were used to describe the following characteristics of the plant communities and their environments: total species richness in quadrats; exotic species richness; endemic species richness; pH; and percentage weight loss on ignition.

Aerial photograph interpretation, field observation and the quadrat data were used to produce a vegetation map that indicates the distribution of floristic communities.

Depending on the characteristics of the data, chi-squared, Students t-test or the Mann-Whitney U test (Siegel 1956) was used to test hypotheses. A community dissimilarity matrix (Bray-Curtis) was calculated using species presence–absence data.

RESULTS AND DISCUSSION

The Flora

One hundred and eighty-five vascular plant taxa were recorded from the Reserve, including 21 trees, 13 ferns, 15 grasses, 44 shrubs, 70 herbs, 18 graminoids (Monocotyledonae not in the Poaceae), and four climbers/scramblers (appendix). Twenty-nine exotic taxa and five Tasmanian endemic species formed part of this total. Species from the families Myrtaceae, Proteaceae, Asteraceae, Epacridaceae, Poaceae and Fabaceae dominate the flora. The list of species is incomplete, as collections took place at a time of the year when many taxa were not evident or identifiable to the species level.

Vegetation

Of the recognised vascular plant communities in Tasmania (Kirkpatrick *et al.* 1995), the Coal River Gorge Nature Reserve contains *Eucalyptus obliqua–Acacia dealbata–Olearia argophylla* wet sclerophyll forest; *E. obliqua–O. lirata–Pultenaea juniperina* wet sclerophyll forest; inland *Allocasuarina* low forest; heathy *E. amygdalina* forest on sandstone; heathy *E. tenuiramis* forest; shrubby *E. obliqua* forest; *Gonocarpus tetragynus–Stylidium graminifolium–Pteridium esculentum* heath.

The vegetation map differentiates three dry sclerophyll and two wet sclerophyll communities (fig. 4). These plant communities are described by their dominant species, faithful species, species richness, the occurrence of exotic and endemic species, vegetation physiognomy and tree basal areas. Their structural and floristic characteristics are summarised in tables 1 and 2.

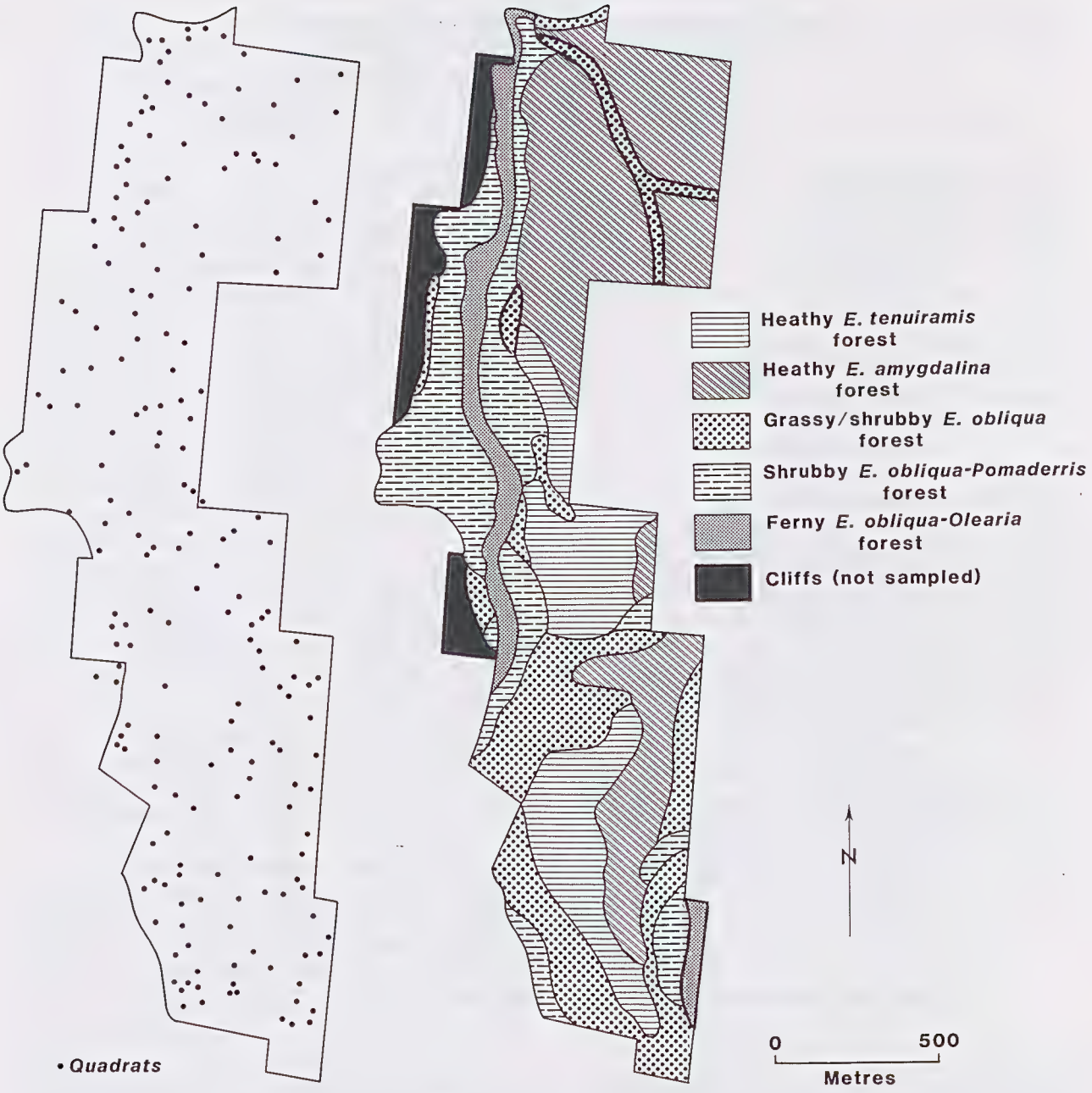

FIG. 4 — Location of sampling sites and plant communities in the Coal River Gorge Nature Reserve.

Group 000 — Heathy *Eucalyptus tenuiramis* forest
This dry sclerophyll community was found in 46 quadrats on the top of the eastern cliffs. It ranges in altitude from approximately 350 to 410 m. Mean tree height is 23 m (table 1). The total basal area is 30.37m^2/ha, and the dominant tree species are *E. tenuiramis* and *E. amygdalina* (table 1). The heathy understorey is variably dominated or co-dominated by the shrubs *Amperea xiphoclada, Aotus ericoides, Epacris impressa* and *Tetratheca labillardierei,* the herb *Stylidium graminifolium* and the fern *Pteridium esculentum.*

Species richness is relatively high (x = 11.50, SD = 2.71) with only a small proportion of the species (x = 1%) being exotics. This community contains few endemic species (x=1%), but these occur in over two-thirds of the quadrats. Species faithful to this group are the shrubs *Pimelea linifolia, Dillwynia sericea* and *Hibbertia riparia,* the herbs *Petrorhagia prolifera* and *Goodenia lanata,* and the parasitic climber *Cassytha pubescens.* The presence of *Amperea xiphoclada* and/or *Aotus ericoides* and the absence of *Pultenaea juniperina* generally discriminate the quadrats in this group from other quadrats. Among recognised communities the group best fits heathy *E. tenuiramis* forest (Kirkpatrick *et al.* 1995). However, there are also small areas of *Gonocarpus tetragynus–Stylidium graminifolium–Pteridium esculentum* heath (Kirkpatrick 1977) that floristically belong to this community.

Group 001 — Heathy *Eucalyptus amygdalina* forest
This dry sclerophyll community was found in 32 quadrats located on the relatively level sites above the eastern cliff and adjacent to the surrounding farmland. It ranges in altitude

TABLE 1
Structural and dominance variables for plant communities

	Community				
	000	001	01	10	11
No. of quadrats	46	28	65	44	17
Classification*	dsf	dsf	dsf	wsf	wsf
Mean % shrub cover	40	35	20	10	<5
Mean % fern cover	<5	<5	<5	10	30
Mean % grass cover	<5	20	25	5	<5
Mean % leaf litter	50	35	30	40	40
Total tree basal area (m^2/ha)	30	27	30	27	22
Eucalyptus tenuiramis basal area	15	5	3	<1	–
E. amygdalina basal area	9	12	3	<1	–
E. obliqua basal area	3	6	13	15	6
E. viminalis basal area	<1	1	3	2	<1
E. globulus basal area	<1	<1	1.5	<1	<1
Acacia dealbata basal area	–	–	1	1.5	2
A. melanoxylon basal area	–	–	<1	1	1.5
Pomaderris apetala basal area	–	–	–	2	5
Olearia argophylla basal area	–	–	–	<1	4
Dead tree basal area	3	4	4.5	5	5
Mean tree height (m)	23	24	23	30	32
Mean shrub height (m)	0.5	0.4	0.7	1.1	1.4
Mean fern height (m)	0.8	0.7	0.8	1.2	0.6
Mean % exotics in quadrats	1	4	10	7	1
% quadrats with exotics	9	36	57	30	6
Mean % endemics in quadrats	1	8	3	2	1
% quadrats with endemics	67	68	25	18	6
Mean tree species richness	2.30	2.00	1.85	2.32	2.29
Mean fern species richness	0.74	0.46	0.65	1.25	2.18
Mean shrub species richness	5.83	4.18	2.17	1.25	0.94
Mean grass species richness	0.50	1.82	1.97	0.82	0.12
Mean herb species richness	1.76	2.64	3.83	2.48	0.59
Mean graminoid species richness	0.33	0.79	0.69	0.20	0.00
Mean species richness	11.50	11.89	11.15	8.32	6.12
Standard deviation species richness	2.71	3.27	4.40	3.35	2.06

* dsf = dry sclerophyll forest, wsf = wet sclerophyll forest.

from approximately 350 to 450 m. Mean tree height is 24 m (table 1). The total basal area is 27.85m^2/ha, not significantly different to that of the heathy *E. tenuiramis* community. *E. amygdalina* is the dominant tree species, with *E. tenuiramis* and *E. obliqua* also being prominent (table 1). The heathy understorey is dominated by the shrubs *Epacris impressa, Pultenaea juniperina, Tetratheca labillardierei* and *Acacia dealbata,* the herbs *Gonocarpus tetragynus* and *Stylidium graminifolium,* and the grass *Poa* spp.

Species richness is relatively high (x = 11.89, SD = 3.27) with only a small proportion of species (x = 4%) being exotic. In comparison to community 000, the exotics occur in a relatively large proportion of quadrats (36%). The mean percentage of endemics in quadrats (x=8%) is higher than that found in any of the other communities.

Species faithful to this group are the shrub *Acrotriche serrulata,* the herbs *Gonocarpus humilis, Viola hederacea* and *Brachyscome aculeata,* and the graminoids *Schoenus apogon* and *Diplarrena moraea.* The quadrats in this community are generally separated from the other quadrats by the presence of *Pultenaea juniperina* and the absence of *Cassinia aculeata, Aotus ericoides, Amperea xiphoclada, Geranium* spp., *Oxalis perennans* and *Senecio linearifolius.* This community fits within the heathy *E. amygdalina* forest on sandstone of Duncan & Brown (1985).

Group 01 — Grassy/shrubby *Eucalyptus obliqua* forest

This dry sclerophyll community was found in 65 quadrats located mostly on the colluvial slopes around the southern end of the Reserve and within the drainage channel running across the northern end. Small pockets are also located along the cliffs within the gorge. It ranges in altitude from approximately 200 to 470 m. Tree height averages 23 m (table 1) *E. obliqua* is the dominant tree species, and *E. viminalis, E. tenuiramis* and *E. amygdalina* all occur as subdominants in fairly even proportions (table 1). The total basal area is 28.69m^2/ha, not significantly different to those of the heathy *E. tenuiramis* and heathy *E. amygdalina* communities. The understorey is dominated by the shrub *Cassinia aculeata,* the herb *Geranium* spp., the graminoid *Lomandra longifolia* and the grass *Poa* spp.

Species richness is relatively high (x = 11.15, SD = 4.40) and is very similar to that of the other dry sclerophyll communities (000 and 001). This community contains a greater proportion of exotic species (x = 10%) than any of the other groups and the exotic species are spread throughout a greater proportion of quadrats (57%). It contains relatively few endemics.

Species faithful to this group are the shrubs *Indigofera australis, Olearia viscosa, Rubus parvifolius* and *Lissanthe strigosa,* the herbs *Drosera* sp., *Geranium* spp., *Corybas* sp., *Carpobrotus rossii, Hypericum gramineum, Scleranthus biflorus, Craspedia glauca, Daucus carota, Lagenifera huegelii, Plantago varia* and *Leptorhynchos squamatus,* and the grass *Themeda triandra.* This community may generally be separated from the others by an occurrence of a combination of species, including at least one from *Cassinia aculeata, Geranium* spp., *Oxalis perennans* and *Plantago varia,* plus at least one from *Lomandra longifolia, Wahlenbergia* sp., *Aira caryophyllea* and *Exocarpos cupressiformis.* These species alone do not sufficiently discriminate this community from the others and, thus, the absences of *Amperea xiphoclada, Aotus ericoides, Bossiaea cinerea* and *Polystichum proliferum* are also an important feature.

From within community 01, three subcommunities may be differentiated. One is characterised by *Senecio linearifolius* and *Olearia lirata.* A second is characterised by *Exocarpos cupressiformis, Plantago varia* and *Aira caryophyllea.* A third is dominated by *Allocasuarina verticillata,* with an understorey of *Lomandra longifolia* and grass species. This latter subcommunity is confined to a small pocket on a north-west facing cliff at the southern end. It falls within the inland *Allocasuarina* low forest of Duncan & Brown (1985), whereas the remainder of community 01 falls within their shrubby *Eucalyptus obliqua* forest.

Group 10 — *Eucalyptus obliqua–Pomaderris apetala* wet sclerophyll forest

This wet sclerophyll community was found in 44 quadrats. These were located along the colluvial slopes within the gorge. It is situated predominantly below an altitude of 300 m. Mean tree height is 30 m, taller than the previous communities (table 1). The total tree basal area is 26.71 m^2/ha, slightly lower than that of the communities described previously. There are many standing dead trees (table 1). *E. obliqua, Pomaderris apetala* and *Acacia dealbata* are the dominant tree species, with the former constituting the tallest stratum. The understorey is dominated by the herb *Senecio linearifolius,* the fern *Pteridium esculentum* and the grass *Poa* spp.

Species richness is generally lower (x = 8.32, SD = 3.35) than that observed within the dry sclerophyll communities, and the proportion of exotic species in quadrats (x = 7%) is similar to that of communities 000 and 01. The proportion of endemic species is relatively low (x = 2%), and they occur in a relatively low proportion of quadrats (18%).

Species faithful to this community are the shrubs *Acacia verniciflua, Rosa rubiginosa* and *Olearia phlogopappa,* the herbs *Lagenifera stipitata, Ranunculus lappaceus, Plantago major* and *Senecio jacobaea,* the climber *Clematis aristata* and the graminoids *Lepidosperma laterale* and *Juncus pallidus.* The quadrats in this group are generally distinguished from other quadrats by the presences either of *Pomaderris apetala* and/or *Polystichum proliferum,* or of *Pteridium esculentum* and/or *Poa* spp., and an absence of *Dicksonia antarctica, Lomandra longifolia, Exocarpos cupressiformis, Aira caryophyllea* and *Plantago varia.* This community falls within the *Eucalyptus obliqua–Olearia lirata–Pultenaea juniperina* wet sclerophyll forest of Kirkpatrick *et al.* (1988).

Group 11 — *Eucalyptus obliqua–Olearia argophylla* wet sclerophyll forest

This wet sclerophyll community is located predominantly along the Coal River and occurred in 17 quadrats. It is situated below an altitude of 260 m. The mean tree height is 32 m, the tallest for any community (table 1). The total basal area (x = 22.60, SD = 8.04) for this community is considerably smaller than those previously observed. There are many standing dead trees (table 1). The dominant tree is *E. obliqua. Pomaderris apetala* and *Olearia argophylla* dominate the second stratum. The understorey is dominated by the shrub *Coprosma quadrifida* and the ferns *Dicksonia antarctica* and *Polystichum proliferum. Dicksonia antarctica* is the only species faithful to this group.

This community exhibits the lowest species richness (x = 6.12, SD = 2.06), a low proportion of exotic species (x = 1%) and a low proportion of endemics (1%). This group may generally be differentiated from the other communities by the presence of *Dicksonia antarctica* and/or at least two species from *Coprosma quadrifida, Olearia argophylla, Polystichum proliferum* and *Pomaderris apetala.* Also the absence of *Poa* spp., *Acaena novae–zelandiae, Viola hederacea* and *Geranium* spp. are diagnostic. This community falls within the *E. obliqua–Acacia dealbata–Olearia argophylla* wet sclerophyll forest of Kirkpatrick *et al.* (1988).

The dry sclerophyll communities from the Reserve are similar in structure and floristics to those described from sandstone elsewhere in the Southern Midlands and Derwent Valley (Hogg & Kirkpatrick 1974, Duncan & Brown 1985). The wet sclerophyll forest communities clearly belong to types widespread in Tasmania (Kirkpatrick *et al.* 1988).

Community Relationships

Vascular plant species richness exhibits a trend from high values in the dry sclerophyll communities to relatively low values in the wet sclerophyll communities (table 1). This trend is also shown in shrub species richness. Fern species richness shows the reverse trend. Tree species richness exhibits little variation, except that it declines slightly in the grassy/shrubby *E. obliqua* community, and graminoid richness is greatest in the heathy *E. amygdalina* and grassy/shrubby *Eucalyptus obliqua* communities. Grass and herb species richness are greatest in the grassy/shrubby *E. obliqua* community.

The heathy *E. tenuiramis* community and the ferny *E. obliqua–Olearia* community are the most dissimilar communities in the Reserve (table 3). The heathy *E. tenuiramis* and the heathy *E. amygdalina* communities are the most similar communities. The heathy *E. amygdalina* community and grassy/shrubby *E. obliqua* community are the next most similar groups. As could be expected, communities occurring in adjacency exhibit a higher degree of floristic similarity with each other than with those more distant, indicating an easily observable continuum of variation related to topographic position.

TABLE 2
Percentage frequency of species by group*

TWINSPAN group†	000	001	01	10	11
Number of quadrats	46	28	65	44	17
Amperea xiphoclada	93.48	21.43	1.54	–	–
Epacris impressa	91.30	57.14	12.31	–	–
Aotus ericoides	86.96	17.86	–	–	–
Pteridium esculentum	73.91	46.43	61.54	68.18	17.65
Stylidium graminifolium	67.39	57.14	35.38	4.55	–
Banksia marginata	54.35	21.43	6.15	–	–
Eucalyptus tenuiramis	47.83	21.43	6.15	2.27	–
Bossiaea cinerea	34.78	7.14	–	–	–
Leucopogon collinus	32.61	7.14	–	–	–
Daviesia ulicifolia	28.26	25.00	6.15	–	–
Oxylobium ellipticum	23.91	14.29	1.54	–	–
Leucopogon ericoides	21.74	10.71	–	–	–
Astroloma pinifolium	21.74	10.71	–	–	–
Exocarpos cupressiformis	19.57	14.29	18.46	–	–
Leptospermum scoparium	17.39	3.57	3.08	–	–
Leucopogon virgatus	13.04	3.57	1.54	–	–
Poa spp.	36.96	85.71	80.00	54.55	5.88
Tetratheca labillardierei	78.26	85.71	10.77	–	–
Pultenaea juniperina	8.70	71.43	20.00	–	–
Acacia dealbata	39.13	64.29	60.00	31.82	23.53
Gonocarpus tetragynus	54.35	64.29	24.62	4.55	–
Eucalyptus amygdalina	23.91	50.00	4.62	–	–
Pterostylis spp.	28.26	50.00	16.92	2.27	–
Helichrysum scorpioides	–	32.14	7.69	–	–
Dianella tasmanica	28.26	32.14	15.38	–	–
Aira caryophyllea	4.35	28.57	26.15	–	–
Lomatia tinctoria	4.35	21.43	9.23	–	–
Pimelea humilis	10.87	17.86	12.31	–	–
Dichelachne spp.	–	17.86	1.54	–	–
Stipa spp.	–	14.29	10.77	2.27	–
Goodenia ovata	4.35	10.71	7.69	–	–
Acrotriche serrulata	–	10.71	–	–	–
Gnaphalium collinum	–	10.71	7.69	4.55	–
Cassinia aculeata	2.17	7.14	49.23	11.36	–
Lomandra longifolia	4.35	39.29	46.15	–	–
Geranium spp.	–	–	36.92	20.45	–
Eucalyptus obliqua	10.87	17.86	26.15	15.91	–
Viola hederacea	–	3.57	23.08	22.73	–
Wahlenbergia sp.	6.52	3.57	21.54	–	–
Plantago varia	–	–	21.54	–	–
Oxalis perennans	–	–	21.54	4.55	–
Danthonia spp.	6.52	3.57	13.85	–	–
Anthoxanthum odoratum	–	7.14	13.85	–	–
Senecio sp.	–	–	13.85	6.82	11.76
Hypochoeris radicata	–	3.57	12.31	6.82	–
Senecio lautus	–	–	12.31	–	–
Olearia lirata	–	–	23.08	59.09	23.53
Senecio linearifolius	–	–	29.23	47.73	11.76
Acaena novae–zelandiae	–	–	9.23	29.55	–
Hydrocotyle hirta	–	3.57	4.62	20.45	5.88
Acacia melanoxylon	6.52	–	6.15	15.91	5.88
Galium australe	–	–	6.15	11.36	5.88
Pimelea drupacea	–	–	–	11.36	5.88
Polystichum proliferum	–	–	–	40.91	94.12
Olearia argophylla	–	–	1.54	11.36	76.47
Pomaderris apetala	–	–	7.69	65.91	70.59
Coprosma quadrifida	–	–	3.08	18.18	58.82
Dicksonia antarctica	–	–	–	–	52.94
Hymenophyllum cupressiforme	–	–	–	2.27	17.65
Phymatosorus pustulatus	–	–	–	2.27	17.65
Stellaria flaccida	–	–	–	11.36	17.65
Australina pusilla	–	–	1.54	4.55	11.76
Blechnum wattsii	–	–	–	–	11.76
Dichondra repens	–	–	1.54	6.82	11.76
Pittosporum bicolor	–	–	–	2.27	11.76

• Showing those occurring in more than 10% of the quadrats in any one group.
† The species are ordered by their abundance within the group within which they are most abundant.

TABLE 3
Bray-Curtis dissimilarity matrix for plant communities

	000	001	01	10	11
000	0.0000	0.3983	0.6370	0.8073	0.9188
001	0.3983	0.0000	0.4878	0.7652	0.9105
01	0.6370	0.4878	0.0000	0.5462	0.8203
10	0.8073	0.7652	0.5462	0.0000	0.5809
11	0.9188	0.9105	0.8203	0.5809	0.0000

Environmental Relationships

The surface rock cover is greatest in the wet sclerophyll communities and least in the dry sclerophyll communities. The *E. obliqua–Olearia* community has a significantly higher rock cover than the *E. obliqua–Pomaderris* and dry sclerophyll communities, and the shrubby *E. obliqua–Pomaderris* forest has a higher cover than the dry sclerophyll forests. The grassy/shrubby *E. obliqua* community has a greater rock cover than the heathy *E. tenuiramis* and heathy *E. amygdalina* communities, which exhibit no significant difference between them (table 4).

The slope varies from steep cliffs to relatively level areas on top of the eastern cliff and on the valley floor. The grassy/shrubby *E. obliqua* and *E. obliqua–Pomaderris* communities occur on significantly steeper slopes than the other communities, and the heathy *E. tenuiramis* community occurs on significantly steeper slopes than the heathy *E. amygdalina* community.

The quadrats in the *E. obliqua–Olearia* wet sclerophyll community occur significantly more on southerly and easterly aspects than on other aspect classes. The quadrats in the *E. obliqua–Pomaderris* wet sclerophyll forest occur significantly more on southwesterly and northeasterly aspects. The quadrats in the dry sclerophyll communities occur significantly more on westerly and northerly aspects.

The soils in the heathy *E. tenuiramis* and heathy *E. amygdalina* communities are grey to brown, stony fine sandy loams. Depth ranges from 0.25 to 0.35 m. The soils of the grassy/shrubby *E. obliqua* and *E. obliqua–Pomaderris* communities are predominantly brown and are loam to fine sandy loams. Soil depth usually approximates 0.95 m. The soils of the *E. obliqua–Olearia* community are dark grey to dark brown-black and are fine loamy sands to silty clays with a moderate to low permeability. Soil depth usually approximates 1.4 m.

The heathy *E. tenuiramis* community is located within a significantly more acidic edaphic environment than any of the other communities, and the heathy *E. amygdalina* community occurs on more acidic soils than the grassy/shrubby *E. obliqua* community.

The only significant differences in the percentage weight loss on ignition involved the heathy *E. amygdalina* community, which had a lower value than both the *E. obliqua–Pomaderris* community and the *E. obliqua–Olearia* community.

The above data indicate that moisture availability is a major correlate of variation in the vegetation of the reserve. The water-holding capacity of the soils increases from the cliff top to the alluvial flats as a result of both increasing soil depth and a higher proportion of fine particles. Overland flow and ground water would tend to augment the amount of moisture available to be held in the soils of the lower slopes. Also, the magnitude of the impact of insolation on evapotranspiration generally decreases along the vegetation continuum from heathy *E. tenuiramis* dry sclerophyll forest to *E. obliqua–Olearia argophylla* wet sclerophyll forest as a result of variation in aspect and the effect of shading from the cliffs.

Tree height has been observed to be related to moisture status, with greater moisture availability being reflected in greater height (Kirkpatrick & Nunez 1980). The vegetation of the Reserve shows a trend in increasing eucalypt and shrub height from the dry sclerophyll communities to the wet sclerophyll communities (table 1), which coincides with the putative increase in soil moisture. The high proportion of dead trees in the wet sclerophyll forests might reflect a failure of downslope flow during the dry summers immediately preceding data collection (cf. Kirkpatrick & Marks 1985).

TABLE 4
Environmental variables for plant communities

Community	000	001	01	10	11
No. of quadrats	46	28	65	44	17
soil colour	dark grey	dark brown	dark brown	dark brown	black
soil depth (m)	0.25–0.35	0.25–0.35	0.95	0.95	1.40
Mean pH	5.0	5.7	6.0	6.2	6.0
Standard deviation pH	0.7	0.7	0.8	1.0	1.6
Mean % weight loss on ignition	9.6	7.8	10.3	10.8	12.4
Standard deviation weight loss on ignition	5.0	4.3	6.6	5.4	7.2
Mean % bare ground	30	15	20	20	20
Mean % rock cover	<5	<5	5	10	20
Mean degree ground slope	5	<5	20	16	5
Aspect*	2.5	2	2	3	4

* Aspect coded on ecological similarity as follows: 1 = NW (driest aspect); 2 = W, N; 3 = SW, NE; 4 = S, E; 5 = SE (wettest aspect).

Our limited data related to soil nutrient availability, pH and soil organic content, also indicates an increase from the cliff top to the alluvial flats. However, the magnitude of the differences is much less than with the attributes related to moisture availability. Both pH and organic content can be as much a function of the vegetation type as a cause of its differentiation. For example, the litter of *Pomaderris* is know to be rich in calcium, which would increase pH (Ashton 1976), and soil organic content is a partial function of vegetation productivity (Attiwill & Leeper 1987). Nevertheless, soils could be expected to be naturally more fertile on the lower slopes, as a result of downslope movement of nutrients through leaching and erosion over time, and because the rocks that tend to form cliff tops are among the more siliceous in a sedimentary series. Certainly, the transition from scleromorphic understoreys to those with substantial components of grasses and broad-leaved shrubs, as recorded in the Coal River Gorge, is typically associated with increasing nutrient status (e.g. Specht 1974).

The codirectionality of moisture and nutrient status makes it impossible to tease out their exact contributions to variation in the vegetation. These gradients may be reinforced by a feedback mechanism between environment, vegetation and litter characteristics and fire frequency, such that fire is least frequent in the valley flats and most frequent on the cliff tops. However, apart from the observation that fire has been more recent on the cliff top than in the valley, we have no data on this subject.

Conservation Significance and Management

With one exception the species and floristic communities identified in this study are considered to be well reserved (Kirkpatrick *et al.* 1995). The heathy *Eucalyptus tenuiramis* forest which was once widespread in the southern Midlands and Derwent Valley (Williams 1991) is that exception. The Coal River Gorge Nature Reserve is its sole security.

The nature of the Coal River Gorge poses a number of problems for management. Firstly, it does not occupy a complete catchment. It is situated mostly in a valley and as a result is subjected to runoff from the surrounding pastures on the hill tops. Secondly, it is long and narrow with a correspondingly high perimeter to area ratio. And thirdly, its relatively small size (209 ha) means that it is at risk from a single event, such as fire.

However, the Reserve is contiguous with other relatively undisturbed areas on private property. Much of this land is likely to remain unmodified due to its inappropriateness for agricultural or grazing purposes, but it is realistic to assume that clearance will continue on suitable land. There is a need to encourage the retention of this native bush surrounding the Reserve for a number of reasons. Firstly, it increases the effective size of the Reserve; and, secondly, it acts as a buffer zone between the Reserve and farmed lands.

Exotic species invasion into the Reserve occurs from surrounding private property; and from water-borne seeds carried by the Coal River. Although exotic species, such as blackberries, were observed growing adjacent to the river, there is no evidence that they are invading the surrounding wet sclerophyll environment. The majority of exotic species invasion is occurring along the interface between the Reserve and farmland.

We recommend that the presence of willow trees (*Salix alba*) in the Coal River at the southern end of the Reserve be monitored to ensure that they are not being dispersed upstream. The majority of exotic species observed in the Reserve are herbaceous and do not seem to threaten the native species.

The southern end of the Reserve is subjected to grazing by sheep and cattle from adjacent private property. The cliff line and adequate fencing on most Reserve boundaries appear to prevent grazing from occurring in the bulk of the Reserve. We recommend that grazing be totally excluded from the Reserve by the improvement of the boundary fence.

Fire is an integral part of the ecology of the plant communities in the Reserve. The amount of dead wood resulting from extensive tree dieback in both the dry and wet sclerophyll communities may increase the severity of fire if it occurs. Fire sensitive species, such as *Olearia argophylla,* which gain some protection from fire in the moist gully location, may have their protection decreased by the dead wood which acts as a source of fuel.

The control of fire regimes in dry sclerophyll vegetation is important in management for conservation. For example, fire regimes of less than ten years are known to reduce species richness in most sedgey and heathy dry sclerophyll communities and a regime of less than 20–25 years reduces richness in shrubby communities (Williams 1991). Conversely, richness also declines in these dry sclerophyll communities if the fire-free period is too great.

We recommend that fire be used as a management tool in the dry sclerophyll vegetation if the fire free period becomes great enough to put species richness at risk. Fire should not normally be used as a management tool in the wet sclerophyll vegetation as the need for it is so infrequent and accidental fires are likely to provide for that need.

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APPENDIX
Higher plant species observed in the Coal River Gorge Nature Reserve

Trees
Acacia dealbata
A. melanoxylon
Allocasuarina verticillata
+Asterotrichion discolor
Banksia marginata
Bedfordia salicina
Bursaria spinosa
+Eucalyptus amygdalina
E. brookeriana
E. globulus
E. obliqua
E. ovata
+E. tenuiramis
E. viminalis
Exocarpos cupressiformis
Olearia argophylla
**Pinus radiata*
Pittosporum bicolor
Pomaderris apetala
P. elliptica
**Salix alba*

Shrubs
Acacia gunnii
A. verniciflua
Acrotriche serrulata
Amperea xiphoclada
Aotus ericoides
Astroloma humifusum
A. pinifolium
Bossiaea cinerea
Cassinia aculeata
Coprosma hirtella
C. quadrifida
Cyathodes glauca
Daviesia latifolia
D. ulicifolia
Dillwynia sericea
Epacris impressa
Goodenia ovata
Ozothamnus ferrugineus
O. obcordatum
O. thyrsoideus
Hibbertia riparia
Indigofera australis
+Leptospermum glaucescens
L. lanigerum
L. scoparium
Leucopogon collinus
L. ericoides
L. virgatus
Lissanthe strigosa
+ Lomatia tinctoria
Olearia lirata
O. phlogopappa
O. ramulosa
O. viscosa
Oxylobium ellipticum
Persoonia juniperina
Pimelea drupacea
P. humilis
P. linifolia
Pomaderris pilifera
Pultenaea juniperina
** Rosa rubiginosa*
Tetratheca labillardierei
Zieria arborescens

Climbers/Scramblers
Cassytha pubescens
Clematis aristata
** Rubus fruticosus*
R. parvifolius

Herbs
Acaena novae-zelandiae
A. ovina
** Acetosella vulgaris*
Ajuga australis
** Anagallis arvensis*
Australina pusilla
Brachyscome aculeata
Cardamine sp.
Carpobrotus rossii
**Centaurium erythraea*
** Centranthus ruber*
Chrysocephalum apiculatum
C. semipapposum
** Cirsium arvense*
** C. vulgare*
**Conium maculatum*
Craspedia glauca
Crassula sieberiana
Cynoglossum australe
Myosotis exarrhena
** Daucus carota*
Dichondra repens
Drosera sp.
Epilobium sp.
Galium australe
** Geranium dissectum*
G. spp.
Gnaphalium collinum
Gonocarpus humilis
G. tetragynus
G. teucrioides
Goodenia lanata
Helichrysum scorpioides
Hydrocotyle hirta
Hypericum gramineum
** Hypochoeris radicata*
Lagenifera huegelii
L. stipitata
** Leontodon taraxacoides*
Leptorhynchos squamatus
Oxalis perennans
Pelargonium australe
** Petrorhagia prolifera*
** Plantago major*
P. varia
Poranthera microphylla
Ranunculus lappaceus
R. pumilio
Rorippa dictyosperma
Scleranthus biflorus
** Senecio jacobaea*
S. lautus
S. linearifolius
S. sp.
** Sonchus asper*
** S. oleraceus*
** Spergularia rubra*
Stackhousia monogyna
Stellaria flaccida
** S. graminea*
** S. media*
S. pungens
Stylidium graminifolium
** Trifolium sp.*
Urtica incisa
** Verbascum thapsus*
Veronica calycina
Viola hederacea
Wahlenbergia quadrifida
W. sp.

Grasses
Agrostis spp.
** Aira caryophyllea*
** Anthoxanthum odoratum*
** Cynosurus echinatus*
Danthonia spp.
Deyeuxia quadriseta
Dichelachne spp.
Ehrharta stipoides
Elymus scabrus
** Holcus lanatus*
Poa labillardierei
P. rodwayi
P. sieberiana
Stipa spp.
Themeda triandra

Graminoids
Bulbine bulbosa
Carex appressa
C. sp.
Chiloglottis reflexa
Corybas sp.
Dianella revoluta
D. tasmanica
Diplarrena moraea
Isolepis cernua
Juncus pallidus
J. pauciflorus
Lepidosperma laterale
Lomandra longifolia
Luzula sp.
Pterostylis spp.
Schoenus apogon
Tetraria capillaris
Triglochin procera

Ferns
Adiantum aethiopicum
Asplenium flabellifolium
A. terrestre
Blechnum nudum
B. penna-marina
B. wattsii
Dicksonia antarctica
Hymenophyllum cupressiforme
Pellaea falcata
Phymatosorus pustulatus
Pleurosorus rutifolius
Polystichum proliferum
Pteridium esculentum

* introduced species
\+ Tasmanian endemic species

THE DISTRIBUTION, ECOLOGY AND CONSERVATION NEEDS OF *COLOBANTHUS CURTISIAE* WEST

Louise Gilfedder and J.B. Kirkpatrick

(with four tables and two text-figures)

GILFEDDER, L. & KIRKPATRICK, J.B., 1996 (30:vi): The distribution, ecology and conservation needs of *Colobanthus curtisiae* West. *Pap. Proc. R. Soc. Tasm.* 130(1): 25–30. ISSN 0080–4703. Department of Geography & Environmental Studies, University of Tasmania, GPO Box 252C, Hobart, Australia 7001 (JBK and formerly LG), LG now Parks and Wildlife Division, DELM, GPO Box 44A, Hobart, Tasmania, Australia 7001 (LG).

Colobanthus curtisiae is known from only 16 populations, most of less than 100 individuals, in the Midlands and Northeastern Highlands of Tasmania. The species occurs in phytosociologically diverse grassy vegetation from 160 m to 1300 m above sea level. This vegetation is rich in herbs and introduced plants, and has much bare ground. *C. curtisiae* germinants were observed in two grazed sets of permanent quadrats but were absent from ungrazed plots. The species is vulnerable to pasture improvement and land clearance and to the lack of disturbances which create bare ground. It requires protection and appropriate management in the lowland part of its range.
Key Words: *Colobanthus curtisiae*, endangered plant, germination, grazing, threatened plant, Tasmania.

INTRODUCTION

The dicotyledonous perennial herb *Colobanthus curtisiae* West was discovered by Rod Fensham in 1985 at Campbell Town Cemetery. This population was eliminated a week later in a cleanup. Several years later populations were located on a roadside at Tunbridge and from Ben Lomond National Park (Davies & Davies 1989), and the species was subsequently described from this material (West 1991). *C. curtisiae* is a Tasmanian endemic small rosette herb in the Caryophyllaceae. It resembles *C. apetala* but differs in its longer and narrower sepals and its colliculate testa patterning (West 1991). It is a grassland and grassy woodland plant. These ecosystems have suffered severe habitat destruction or degradation since the European invasion (Fensham & Kirkpatrick 1989, Fensham 1989, Gilfedder & Kirkpatrick 1995).

C. curtisiae is listed as endangered on both the national and state levels (Endangered Flora Network 1993; Flora Advisory Committee 1994).

This paper maps the known distribution of the species, places it in its environmental and phytosociological context, describes the germination behaviour of one lowland population, reports the responses of the species to different grazing regimes in three lowland populations and draws conclusions on the conservation needs of the species.

METHODS

Distribution, Phytosociology and Environment

Searches were made for additional populations of the species in apparently suitable habitats, the search pattern being modified as newly discovered populations revealed further aspects of its preferences. In some cases, additional populations were found in the course of other investigations. Floristic and site data were recorded for each located population. Quadrats measuring 1 × 10 m were subjectively placed in the least disturbed vegetation in which *C. curtisiae* occurred at each site, and all observable vascular plant taxa within the quadrat noted. Species nomenclature follows Buchanan (1995). Altitude, surface geology, soil surface pH (using a CSIRO soil-testing kit) and soil type were noted or measured in the field. The slope and aspect of each site were determined using a clinometer and compass respectively. Climatic data were derived for each site using the Bioclimatic Prediction System (Busby 1988).

The polythetic divisive technique TWINSPAN (two-way indicator species analysis) (Hill 1979) was used to obtain a sorted table. This table was then manually resorted to improve its organisation, with the aim of placing quadrats with similar species composition close together and species with similar quadrat distributions close together. This was necessary as TWINSPAN is a poor sorter of species and inverts the quadrat sequences on division.

The percentage frequencies of other vascular plant taxa in quadrats with *C. curtisiae* were determined, as were the percentage frequencies for all taxa occurring in the rest of the grassy ecosystem data set (Kirkpatrick *et al.* 1988). A list was made of those species that occurred in 10% or more of quadrats in either of the databases, the list being separated into those occurring more frequently with *C. curtisiae* and those occurring more frequently without *C. curtisiae*. These species were then classified into lifeform groups (shrub or tree; grass, graminoid, geophyte; herbs) and two origin groups (Tasmanian native; other).

Population Monitoring

Population numbers were monitored from 1990–94 at three low altitude locations (table 1) with different grazing management regimes. At Tunbridge, on a roadside which is used on a regular basis as a stock route and where the population numbers less than 50 individuals, seven permanent plots (0.5 × 0.5 m) were established within the population. At the South Esk River site, which is a heavily grazed native pasture with ± 1000 *C. curtisiae* individuals, two transect lines were placed through the population, and 23 contiguous quadrats measuring 0.5 × 0.5 m were monitored. A third population (<100 individuals) was monitored at a site on a Holocene lunette west of Campbell Town. This site had been previously grazed but stock had been excluded

TABLE 1
Localities with *Colobanthus curtisiae*

Locality	Altitude (m)	Geology	Tenure	Species richness	Dominant tree species
Ben Lomond	1300	sandstone	national park	20	above treeline
Buffalo Brook	300	sand	private	19	*Acacia mearnsii*
Campbell Town 1*	160	sand	private	n.a.	*Eucalyptus pauciflora*
Campbell Town 2	310	dolerite	private	26	*E. viminalis*
Campbell Town 3	200	basalt	cemetery	extinct	*E. pauciflora*
Fingal Tier	700	dolerite	state forest	20	*E. amygdalina*
Lagoon of Islands	760	dolerite	HEC	21	*E. obliqua*
Andover	430	sandstone	private	28	*E. pauciflora*
Near Lagoon	240	sand	private	17	*A. dealbata*
Ouse River	400	sandstone	private	10	*E. dalrympleana*
Shannon River 2	360	sandstone	private	14	*E. viminalis*
South Esk River*	180-240	dolerite	private	27	*E. pauciflora*
Shannon River 1	620	dolerite	private	10	*E. rubida*
Swanston	240	sandstone	private	15	*E. pauciflora*
Tunbridge*	240	dolerite	roadside	24	*E. rodwayi*
Valleyfield	n.a.	n.a.	private	n.a.	n.a.
Woodbury	n.a.	sandstone	private	n.a	*E. viminalis*

n.a. = not available.
* Sites where the species was monitored from 1990–94.

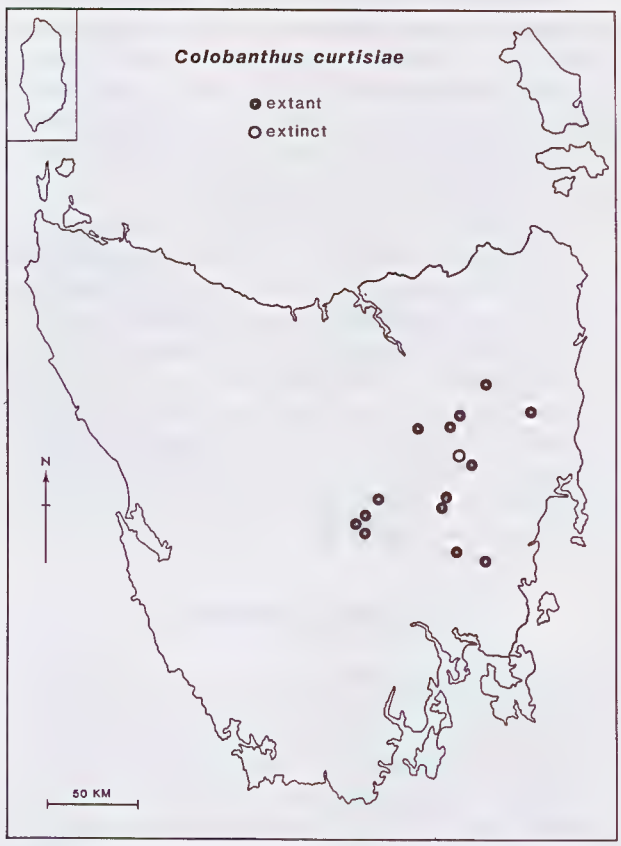

FIG. 1 — Extant and past localities for Colobanthus curtiseae

for several years. A 5 m transect line was placed through the population of *C. curtisiae* and 11 contiguous quadrats measuring 0.4 × 0.4 m were placed at 0.5 m intervals. The number of adult individuals, the number of recent germinants, the number of flowers per plant, and the Braun-Blanquet cover scale (Mueller-Dombois & Ellenberg 1974) for grasses, herbs, exotic plants and bare ground were recorded at yearly intervals. Data were converted to density per square metre.

Germination

Germination tests were conducted on seeds of *C. curtisiae* collected from the South Esk site on 12 February 1991. The seed was stored in bags at ambient room temperature. Germination tests were carried out by placing the seed on moist double layers of filter paper (Whatman No. 1) in 90 mm Petri dishes on 4 June 1991. For each trial there were five replicates of twenty seeds placed in randomised blocks. The seeds were checked twice daily and watered with distilled water when necessary, ensuring that the filter paper was maintained in a moist but not wet condition. The seed was germinated in an incubator in dark conditions, with the seeds being exposed to light when watered. Four temperatures were used for each replicate: 5°, 10°, 15° and 20°C. There was no pre-treatment.

RESULTS

Distribution, Phytosociology and Environment

C. curtisiae was found at 14 additional sites, and survives at two of the previously known sites (fig. 1, table 1). It occurs on gentle slopes between 160 and 1300 m (median = 310 m) in elevation in inland Tasmania. Mean annual rainfall varies

from 530 mm in the lowland Midlands area to more than 1400 mm on Ben Lomond, with a median of 607 mm. The mean temperature of the warmest month varies from 10.5° to 16.1°C, with a median of 15.1°C. The mean temperature of the coolest month varies from 1.6° to 6.5°C. Soils are predominantly sandy loams derived from sandstone or Holocene sands, but the species also occurs on clay loams derived from dolerite and basalt. Rock cover is absent at most sites. The median soil pH is 6 (range 4.5–8.5).

The median native species richness was 19/10m^2 (range 7–32). The median exotic species richness was 6/10m^2 (range 0–11). The median of Tasmanian endemic species richness was 1 (range 1–7).

The native species occurring in more than 40% of the quadrats with *C. curtisiae* were, in order from high to low co-occurrence: *Scleranthus biflorus, Carex breviculmis, Oxalis perennans, Acaena novae-zelandiae* and *Poa labillardierei.* Herbs and introduced taxa proved to have higher frequencies in the *C. curtisiae* data set than in the grasslands and grassy woodlands data set (table 2). The reverse pertained for grasses (table 2).

Bray-Curtis distance values (Minchin 1990) between quadrats varied from a high of 0.9070 between a lowland and an alpine quadrat to 0.2143 between two lowland quadrats. At least four groups of quadrats can be perceived in the sorted table (table 3), although the variation is more or less continuous. Group I is best characterised by the relatively faithful taxa in species group A. The most constant of these taxa are *Wahlenbergia* spp., *Danthonia carphoides* and *Plantago varia.* Group II has many highly faithful taxa, these being in species group C, but none of these is highly constant. Its constant species are *Aira caryophyllea, Oxalis perennans, Scleranthus biflorus, Acaena novae-zelandiae* and *Poa labillardierei.* The relatively faithful species in quadrat group III are in species group K. Of these, only *Elymus scabrus* has a high degree of constancy. Other constant species are *Poa labillardierei, Acetosella vulgaris, Scleranthus biflorus* and *Aira caryophyllea.* The Ben Lomond quadrats form group IV, which is best characterised by the highly faithful and constant *Plantago paradoxa* and *Senecio pectinatus.*

Population Monitoring

Between 1990 and 1994, *C. curtisiae* increased in density in the heavily grazed plots (South Esk), decreased in density in the intermittently grazed plots (Tunbridge) and changed little in the ungrazed plots (Campbell Town) (table 4). Successful establishment of germinants was observed from 1990–94 in the heavily grazed plots (table 4), with the number of new germinants being higher in 1994 than 1990. Germinants were also observed in the occasionally grazed plots, but only in 1994. No germinants were observed in the ungrazed plots. The density of flowers increased between 1990 and 1994 in the heavily grazed plots, while decreasing in the other plots. In 1994, the heavily grazed plots had a higher percentage cover of bare ground, herbaceous plants and exotic species than the other sites (table 4).

Germination

High germination levels of *C. curtisiae* were achieved at 5°C (73% of seed) and 10°C (69%) (figure 2), with only 2% of seeds germinating at 15°C and none at 20°C. Germination at 5°C was delayed until after day 30. The seed of *C. curtisiae* was observed in profusion in an ants nest at the South Esk site. Fifty to 100 seeds can be obtained per inflorescence.

DISCUSSION

C. curtisiae has a wide phytosociological and environmental range, suggesting that the cause of its rarity is not the lack of substantial areas of suitable physical environment, at least before the European invasion. Our data from one lowland site indicate that *C. curtisiae* is an easily germinated species with a large seed output, suggesting that reproductive problems are also unlikely to be a cause of its rarity. Our permanent plot observations suggest that it is able to survive and successfully regenerate with a level of stock grazing which renders other threatened taxa of grassy ecosystems, such as *Lepidium hyssopifolium* and *Barbarea australis,* locally

TABLE 2
Composition of lifeform groups associated with *Colobanthus curtiseae**

Lifeform group	More common with *C. curtiseae*		Less common with *C. curtiseae*	
	Observed	Expected†	Observed	Expected†
Trees and Shrubs	5	7	10	8
Grasses	8	12	18	14
Graminoids	5	6	7	6
Geophytes	2	3	4	3
Herbs	37	29	23	31
Introduced species	17	10	4	11

* The number of species in different lifeform and origin groups that are more frequent in vegetation with *C. curtiseae* than in Tasmanian grasslands and grassy woodlands and vice-versa. Only species occurring in more than 10% of the quadrats in at least one of the data sets are included.
† As in Chi-squared.

TABLE 3
Sorted table for quadrats with *Colobanthus curtisiae*

Group	I	II	III	IV
	1 1 1	1 1	1 1 1	1 11
Quadrat (1)	127	85694480	31327	56
A				
+Schoenus absconditus	11-	1----1--	-----	--
Wahlenbergia spp.	111	---1----	-----	--
Danthonia carphoides	111	---1----	-----	--
Plantago varia	111	1-------	----1	--
Pentapogon quadrifidus	-11	--------	-----	--
Convolvulus erubescens	-11	--------	-----	--
Wahlenbergia stricta	-11	--------	-----	--
Hibbertia riparia	-11	--------	-----	--
Lissanthe strigosa	-11	--------	-----	--
**Trifolium glomeratum*	-11	--------	-----	--
Stipa semibarbata	-11	--1-----	-----	--
Wurmbea dioica	-11	--1-----	-----	--
Acaena ovina	-11	--1-----	-----	--
B				
Hypoxis glabella	1--	1---1---	1----	--
**Briza minor*	-1-	1-1-1---	-----	--
Dichondra repens	-11	--1--1--	----1	--
Themeda triandra	-11	1--11--1	-----	--
Leptorhynchos squamatus	-11	1-1-1--1	-----	--
Chrysocephalum apiculatum	-11	1--11--1	1----	--
Poa hookeri	-11	--1-----	11---	--
C				
Lomandra nana	---	-11-----	-----	--
**Centaurium erythraea*	---	1-1-----	1----	--
Astroloma humifusum	---	--11----	1----	--
**Parentucellia viscosa*	---	--1-1--1	-----	--
**Trifolium subterraneum*	---	--1-1--1	-----	--
Hovea linearis	---	--1-1--1	-----	--
**Plantago coronopus*	---	--1-11-1	-----	--
**Bromus mollis*	---	--1-1-1-	-----	--
Ehrharta stipoides	---	--1111-1	1----	--
Lomandra longifolia	---	--1-11-1	1--1-	--
**Trifolium pratense*	---	----1--1	-----	--
**Cerastium glomeratum*	---	---1--11	-----	--
**Erophila verna*	---	----1-11	-----	--
**Aphanes arvensis*	1--	----1-11	-----	--
Pimelea humilis	-1-	---11---	----1	--
Crassula sieberiana	-1-	----11--	-----	--
Gnaphalium collinum	1--	-----11-	-1---	--
D				
**Moenchia erecta*	---	--1-----	1----	--
+Hibbertia hirsuta	---	---1----	1----	--
E				
Cotula alpina	1--	--------	-----	-1
Hydrocotyle sibthorpioides	1--	--------	-----	-1
Baeckea gunniana	1--	--------	-----	1-
Euchiton traversii	1--	--------	-----	1-
Gonocarpus tetragynus	1--	--------	----1	--
Carex inversa	-1-	--------	----1	--
F				
**Hypochoeris radicata*	11-	111-1--1	11-1-	--
**Aira caryophyllea*	111	11111111	111-1	--
Oxalis perennans	-11	-1111111	11--1	--
**Trifolium dubium*	-11	11--1-11	11--1	--
Scleranthus biflorus	-11	11-11111	11111	--
G Hypericum gramineum	-11	--1-----	-1-11	--
**Leontodon taraxacoides*	-11	---1-1--	11--1	--
H				
+Colobanthus curtisiae	111	11111111	11111	11
Carex breviculmis	111	--1-1111	-1-11	11
I				
Acaena novae-zelandiae	---	1-1111-1	--111	1-
Poa labillardierei	---	--111111	1-111	-1
**Acetosella vulgaris*	-1-	----1111	11-11	--
J				
Pteridium esculentum	---	-1------	---1-	--
Ajuga australis	---	------1-	----1	--
Danthonia pilosa	---	--1-----	----1	--
**Lagenifera stipitata*	---	--1-----	----1	--

Group	I	II	III	IV
	1 1 1	1 1	1 1 1	1 11
Quadrat (1)	127	85694480	31327	56
K				
Elymus scabrus	-11	--------	11-11	--
Daviesia ulicifolia	---	--------	11---	--
Pultenaea pedunculata	---	--------	1-1--	--
Luzula spp.	---	------1-	111--	--
Juncus spp.	---	--------	111--	--
Geranium sessiliflorum	---	--------	-11--	--
Schoenus apogon	---	--------	--11-	--
Lagenifera huegelii	---	------1-	-1-1-	--
**Anthoxanthum odoratum*	---	-----1--	-1--1	--
Acaena echinata	---	--------	-1--1	--
Veronica gracilis	---	---1----	-1-1-	--
**Holcus lanatus*	---	--1-----	-1-11	--
Geranium solanderi	---	--1----1	--111	--
L				
Epilobium spp.	---	--------	--111	11
Ranunculus lappaceus	---	--------	----1	1-
Oreomyrrhis eriopoda	---	--------	----1	-1
M				
Senecio pectinatus	---	--------	-----	11
+Plantago paradoxa	---	--------	-----	11

Species occurring in only one quadrat

11: *Agrostis parviflora, Cardamine* spp., *+Eucalyptus amygdalina, Hydrocotyle capillaris, +Lomatia tinctoria, Poa rodwayi, Veronica calycina, Viola cleistogamoides, Wahlenbergia gracilenta*
2: *Carex iynx, Ptilotus spathulatus, Stipa mollis, Stipa scabra, *Vulpia myuros*
17: *Danthonia laevis, Danthonia setacea*
5: **Erodium cicutarium*
6: *+Australopyrum pectinatum, Microtis* spp., *Thelymitra* spp.
9: *Danthonia caespitosa, Hibbertia serpyllifolia, Lepidosperma gunnii, Opercularia ovata, Opercularia varia, Wahlenbergia gymnoclada*
14: **Bromus diandrus, Carex tasmanica*
4: *Eucalyptus pauciflora*
8: *Callitriche umbonata, *Cirsium vulgare, Luzula flaccida, *Myosotis discolor, *Stellaria media*
10: **Cardaria draba, *Hypochoeris glabra*
13: *Banksia marginata, Hibbertia prostrata*
1: *Asperula conferta, Galium* spp., *Taraxacum aristum*
3: *Asperula gunnii, Eucalyptus rubida, Juncus australis*
12: **Agrostis capillaris, *Cerastium fontanum, *Trifolium repens*
7: *Arthropodium milleflorum, Epilobium hirtigerum, Glycine* spp., *Isolepis nodosa, Linum marginale, *Petrorhagia prolifera, Poranthera microphylla, Pratia pedunculata, Pratia* spp., *Senecio glomeratus, Viola hederacea*
15: *Drosera arcturi, Eriostemon verrucosus, Geranium potentilloides, Gonocarpus serpyllifolius, Helichrysum rutidolepis, +Leptospermum rupestre, +Monotoca empetrifolia, +Orites acicularis, Poa gunnii, Poa costiniana, +Richea acerosa, +Richea gunnii, *Taraxacum officinale*
16: *Agrostis venusta, Bellendena montana, Carpha alpina, Deyeuxia monticola, Leucopogon hookeri, Microseris lanceolata, Ranunculus decurvus, Ranunculus sessiliflorus, Senecio gunnii*

* = introduced species
\+ = Tasmanian endemic species
(1) read quadrat numbers vertically

TABLE 4
Mean and standard error of *Colobanthus curtisiae* and ground cover types per square metre under different management regimes

Location	1990	1994
C. curtisiae/m^2		
South Esk R.	176.9 ± 42.2	278.0 ± 59.8
Tunbridge	143.8 ± 86.9	38.4 ± 11.6
Campbell Town	30.1 ± 15.5	40.9 ± 12.9
new germinants/m^2		
South Esk R.	2.45 ± 1.09	8.70 ± 1.79
Tunbridge	0	2.68 ± 1.86
Campbell Town	0	0
flowers/m^2		
South Esk R.	284.0 ± 62.7	470.4 ± 95.4
Tunbridge	25.0 ± 25.0	1.8 ± 1.8
Campbell Town	137.5 ± 44.3	61.9 ± 28.7
percentage cover of grass (Braun-Blanquet+)		
South Esk R.	3.17 ± 0.16	3.26 ± 0.18
Tunbridge	3.00 ± 0.38	3.57 ± 0.37
Campbell Town	3.82 ± 0.23	4.45 ± 0.34
percentage cover of herbs (Braun-Blanquet)		
South Esk R.	4.04 ± 0.25	3.91 ± 0.22
Tunbridge	3.86 ± 0.34	3.71 ± 0.52
Campbell Town	3.55 ± 0.28	2.27 ± 0.19
percentage cover of bare ground (Braun-Blanquet)		
South Esk R.	3.13 ± 0.25	3.87 ± 0.22
Tunbridge	1.71 ± 0.52	1.29 ± 0.29
Campbell Town	3.18± 0.38	2.91 ± 0.21
percentage cover of exotic species (Braun-Blanquet)		
South Esk R.	3.26 ± 0.20	3.22 ± 0.21
Tunbridge	0.86 ± 0.34	1.29 ± 0.18
Campbell Town	3.18± 0.18	2.18 ± 0.23

1 = <1% cover, 2 = 2-5% cover, 3 = 6-25% cover, 4 = 26-50% cover, 5 = 51-75% cover, 6 = 76-100% cover

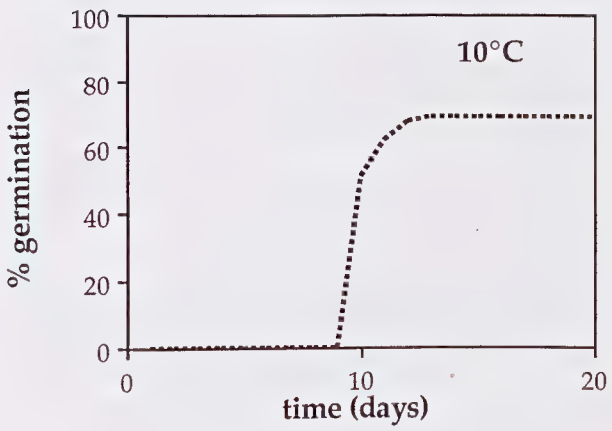

FIG. 2 — Germination curve for Colobanthus curtiseae *at 10°C*

extinct (Cropper 1987; Gilfedder 1994). However, these observations also indicate that bare ground may be necessary for its regeneration. Heavy cattle and sheep grazing provide this bare ground through much of its present range, while in some parts of its range, such as the Tunbridge Tiers Stock Route, individuals regenerate in the bare patches associated with tree roots.

The very limited present distribution of the species is almost certainly due to the loss of most of the Tasmanian grassland and grassy woodland on non-rocky soils within its range to improved pasture and cropland (Fensham & Kirkpatrick 1989). This loss is on-going (Kirkpatrick 1991), so the species deserves to be regarded as endangered, especially given that most of the 16 surviving populations consist of less than 100 individuals.

The major surviving lowland populations of the species need to be protected from pasture improvement and land clearance by mechanisms such as covenanting, management agreements or reservation. Where areas supporting populations have been heavily grazed by stock, it would be prudent to ensure that this form of disturbance continues.

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(accepted 14 May 1996)

THE DISTRIBUTION, ECOLOGY AND MANAGEMENT OF TWO RARE TASMANIAN SEDGES — *SCHOENUS ABSCONDITUS* KUK. AND *CAREX TASMANICA* KUK.

by Louise Gilfedder and J.B. Kirkpatrick

(with five tables and two text-figures)

GILFEDDER, L. & KIRKPATRICK, J.B., 1996 (30:vi): The distribution, ecology and management of two rare Tasmanian sedges — *Schoenus absconditus* Kuk. and *Carex tasmanica* Kuk. *Pap. Proc. R. Soc. Tasm.* 130(1): 31–40. ISSN 0080–4703. Department of Geography and Environmental Studies, University of Tasmania, GPO Box 252C, Hobart, Tasmania, Australia 7001 (JBK and formerly LG), LG now Parks and Wildlife Service, GPO Box 44A, Hobart, Tasmania, Australia 7001 (LG).

The sedges, *Carex tasmanica* and *Schoenus absconditus*, were considered to be threatened species at the national level. They are species of grassland and grassy woodland in the driest parts of Tasmania, *C. tasmanica* being associated with drainage lines, and *S. absconditus* characteristically occurring in *Themeda triandra* grassland, in situations where there is a large amount of intertussock space. Both species proved much more common than previously thought, and both species have been downlisted. They are both well-adapted to mechanical disturbance and sheep grazing. *C. tasmanica* is also herbicide resistant. However, mowing and cattle grazing deleteriously affect *C. tasmanica*. *S. absconditus* can no longer be regarded as a rare or threatened species. However, *C. tasmanica* has disappeared from two localities out of 30 in the past four years and has no substantial populations in any secure reserve. Secure reservation is needed for this vulnerable species.

Key Words: *Carex tasmanica*, conservation, disturbance, grazing, management, *Schoenus absconditus*.

INTRODUCTION

The maintenance of native biological diversity is now a major national policy goal in Australia. If the species level of native biological diversity is to be maintained, rare and threatened taxa need particular attention, as these are most likely to become extinct in the near future. National listings of rare and threatened vascular plant species have been available for Australia for some time (e.g. Briggs & Leigh 1988). These have been based on information on current distributions and population sizes that is often very partial, especially in the cases of sedges (Cyperaceae), rushes (Juncaceae) and grasses (Poaceae), which tend not to be favoured by collectors and which often present identification difficulties. There is a need to gain data on the distribution and ecology of listed species, in order to confirm or reject their listed status and to develop, if necessary, programs for their recovery. In this paper we report such investigations into the distribution, ecology and management of two Tasmanian sedges, *Carex tasmanica* and *Schoenus absconditus*.

Carex tasmanica is a tufted rhizomatous perennial sedge with distinctive coiling of the distal portion of the erect leaves (Curtis & Morris 1994). The leaves may be flat, broad or inrolled, and may be up to 0.4 m long. *S. absconditus* is also a tufted rhizomatous perennial sedge which is distinguished by a very short culm bearing the inflorescence (Curtis & Morris 1994).

Schoenus absconditus was recorded on the national listing as a vulnerable Tasmanian endemic species with a distribution of less than 100 km^2 (Briggs & Leigh 1988). *C. tasmanica* was originally more widespread in its distribution, occurring in eastern Tasmania and in western Victoria, where it is now considered a vulnerable species (Gullan *et al.* 1990). It is also reported as occurring on the Darling Downs of Queensland (Hnatiuk 1990) — although there are no records at the Queensland Herbarium (R. Fensham, pers. comm.). The species has been listed as nationally endangered (Briggs & Leigh 1988) but was not included in the recent national list (Endangered Flora Network 1993), nor listed at the state level by the Flora Advisory Committee (1994).

METHODS

The former and extant distributions of *Carex tasmanica* and *Schoenus absconditus* were determined from herbarium collections, literature references and survey data. Searches were made at these sites and environmentally similar ones. Where either species was located, floristic and site data were recorded. Quadrats measuring 1 x 10 m were subjectively placed in the least disturbed vegetation in which *C. tasmanica* or *S. absconditus* occurred. Presences were recorded for all vascular plant species. Species nomenclature follows Buchanan (1995).

Altitude, surface geology, soil type and surface soil pH (using a CSIRO soil-testing kit) were measured or noted in the field. The slope and aspect of each site were determined, using a clinometer and compass respectively. Climatic data were derived for each site using the Bioclimatic Prediction System (Busby 1988).

The polythetic divisive technique TWINSPAN (two-way indicator species analysis) (Hill 1979) was used to obtain sorted tables for quadrats with each species. These were re-sorted manually and used as the basis for the selection of communities.

The percentage frequencies of species in the quadrats with *S. absconditus* and those with *C. tasmanica* were calculated, as were the percentage frequencies of all species in a grassland and grassy woodland database, consisting of 1206 quadrats. A list was made of those species that occurred in 10% or more of quadrats in any of the databases, the list being separated into those occurring more frequently with *S. absconditus*, those occurring more frequently without *S. absconditus*, those occurring more frequently with *C. tasmanica* and those occurring more frequently without *C. tasmanica*. These species were then classified into lifeform

groups (shrub or tree; grass or graminoid; herb; geophyte) and two origin groups (Tasmanian native; other).

The response of *S. absconditus* to different management regimes was documented by placing transect lines through vegetation under different management containing the species and determining their density. *S. absconditus* plots were established in ungrazed, lightly grazed, heavily grazed situations, and on revegetating gravel pits. The former two situations were at Tunbridge, while the latter two were at Nile. For *C. tasmanica* transects were placed in vegetation at the Queens Domain that was either regularly mown, burned then sprayed with a broadleaf selective herbicide or mulched with woodchips. These transects were monitored from 1991–95 to determine the effect of site management on numbers of *C. tasmanica*. Kruskal-Wallis One-way Analysis of Variance by Ranks and the Mann-Whitney U Test (Siegel 1956) were used to determine if the densities of *S. absconditus* and *C. tasmanica* significantly varied under different management regimes, over time, and in relation to various ground covers.

RESULTS AND DISCUSSION

Distribution, Environment and Phytosociology of *Carex tasmanica*

Carex tasmanica was recorded at 27 locations in northern, eastern and southern Tasmania, and the Midlands (fig. 1). It occurs from sea level to approximately 600 m on a wide range of soil types derived from dolerite, basalt, sandstone and wind-blown sands. The pH of these soils varies from weakly acid to weakly alkaline, with a median value of 7.0. Mean annual precipitation varies from approximately 550 mm to approximately 700 mm, with a median value of 656 mm. Mean precipitation in the driest month varies from approximately 35 mm to 75 mm with a median of 65 mm. The mean temperature of the warmest month varies from 12.3° to 16.3°C with a median value of 15.5°C, and that of the coldest from 4.5° to 8.6°C with a median of 7.0°C.

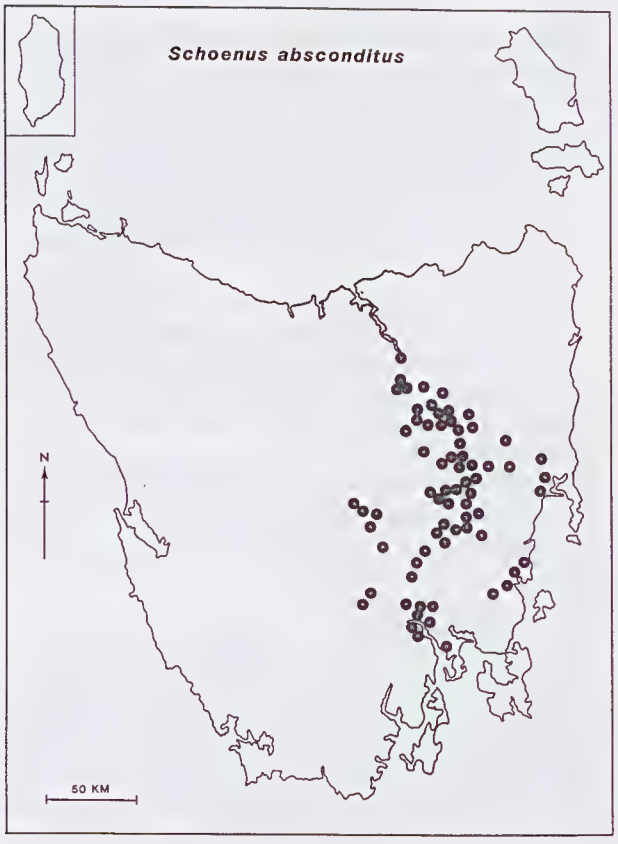


FIG. 1 — Distribution of Schoenus absconditus.

All of the populations are associated with constantly moist places, such as seepage or drainage lines. Tree cover is rare, but the species does occur in woodland and forest communities dominated by *Eucalyptus ovata*. Most of the populations occur in a matrix dominated by exotic species. The percentage of exotic species in quadrats varied from 25 to 90 with a mean of 51. *Carex gunniana*, *Juncus* spp., native *Poa* spp. and *Acaena novae-zelandiae* were the only native taxa to occur in more than 40% of the quadrats with *C. tasmanica*. The exotic species found in more than 40% of the quadrats were *Holcus lanatus*, *Plantago lanceolata*, *Hypochoeris radicata*, *Leontodon taraxacoides* and *Agrostis capillaris*.

The native species that were more abundant with *C. tasmanica* than in the grasslands and grassy woodlands database as a whole were mostly taxa characteristic of the margins of wetlands, including *Leptospermum lanigerum*, *Poa labillardierei*, *Carex gunniana*, *Eleocharis acuta*, *Juncus australis* and *J. pauciflorus*. Thirty of the 43 species that were more abundant with *C. tasmanica* than in the larger dataset were exotics, mostly herbs and perennial grasses (table 1). In contrast, only five of the 73 species that were more abundant in the larger dataset were exotics (table 1).

The high and variable degree of invasion by exotics makes it difficult to perceive strong communities within the sorted table (table 2). However, the left half of the matrix can be distinguished from the right half on the basis of the relatively high constancy and fidelity of the native species: *Asperula conferta*, *Geranium solanderi*, *Veronica gracilis*, *Poa labillardierei* and *Acaena novae-zelandiae*. The right half of the matrix is less strongly distinguished by the relatively high constancy and fidelity of the native species: *Carex gunniana*, *Themeda triandra*, *Hypericum gramineum* and *Juncus pauciflorus*. The former community tends to be associated with sedimentary rocks and streamsides in the inland locations, while the latter tends to occur preferentially on igneous rocks and soaks near the coast.

Distribution, Environment and Phytosociology of *Schoenus absconditus*

Schoenus absconditus was found at more than 70 localities (fig. 2). It has been previously misidentified as the more common *S. apogon*. It occurs in southeastern and eastern Tasmania, being recorded as far north as Launceston. It occurs on soils ranging in texture from sandy loams to clay loams and clays derived from basalt, dolerite, sandstone, mudstone, alluvium and Holocene deposits. These soils vary in surface pH from 6.0 to 9.0 with a median value of 6.5. It ranges in altitude from sea level to 650 m. Mean annual rainfall varies from 450 to 900 mm with a median of 605 mm, with the rainfall in the driest month varying from 20 mm to over 70 mm with a median of 60 mm. The mean temperature of the warmest month varies from 12.6° to 16.3°C with a median of 15.6°C, and that of the coolest month varies from 4.6° to 8.5°C with a median of 6.5°C.

TABLE 1
Composition of lifeform groups associated with *Carex tasmanica* or *Schoenus absconditus**

Lifeform group	More common with *Carex*		Less common with *Carex*	
	Observed	Expected	Observed	Expected
Trees and Shrubs	5	6	10	9
Grasses and graminoids	15	16	28	29
Herbs	23	20	31	34
Geophytes	0	1	4	3
Total	43	43	73	73

Lifeform group	More common with *Schoenus*		Less common with *Schoenus*	
	Observed	Expected	Observed	Expected
Trees and Shrubs	2	6	9	5
Grasses and graminoids	14	19	23	18
Herbs	37	30	22	29
Geophytes	5	3	1	3
Total	58	58	55	55

* The number of species in different lifeform groups that are more frequent in vegetation with either *Carex tasmanica* or *Schoenus absconditus* than in Tasmanian grasslands and grassy woodlands and vice-versa. Only species occurring in more than 20% of the quadrats in at least one of the data sets are included.

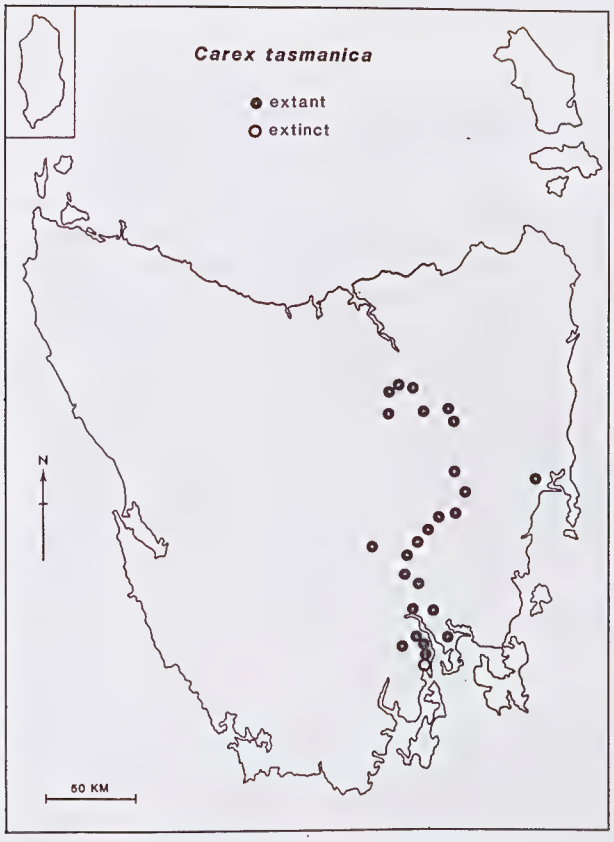


FIG. 2 — Distribution of Carex tasmanica.

Schoenus absconditus occurs in grasslands and grassy woodlands on well-drained sites in which the ground stratum is dominated by kangaroo grass (*Themeda triandra*), wallaby grass (*Danthonia* spp.), tussock grass (*Poa* spp.) and a rich variety of herbs. *Eucalyptus pauciflora* and *E. ovata* are the most common dominants in woodland with *S. absconditus*. Native species tend to dominate the cover and richness of the quadrats. The percentage of exotic species in quadrats varied from zero to 60, with a mean of 22.

The native taxa that occurred in more than 40% of the quadrats with *S. absconditus* were *Themeda triandra*, *Danthonia* spp., native *Poa* spp., *Leptorhynchos squamatus*, *Oxalis perennans*, *Carex breviculmis*, *Geranium solanderi*, *Plantago varia*, *Ehrharta stipoides* and *Pimelea humilis*. Only three exotics were as frequent. These were *Aira caryophyllea*, *Centaurium erythraea* and *Leontodon taraxacoides*. The native species that occurred in more than 10% of the quadrats with *S. absconditus* and had a higher percentage frequency in these than in the grasslands and grassy woodlands data set were mainly perennial herbs. More herbs and geophytes than expected occurred preferentially with *S. absconditus* (table 1). The converse was true for grasses and graminoids, and for shrubs and trees. Eighteen of the 58 species that occurred preferentially with *S. absconditus* were exotics, largely grasses and herbs. Of those 55 species that occurred preferentially in the data set as a whole, only four were exotics.

The sorted table (table 3) is again somewhat diffuse. However, the quadrats divide into two approximately equal sets, one of which is characterised by the following native plants: *Chrysocephalum apiculatum*, *Geranium solanderi*, *Danthonia tenuior*, *Vittadinia muelleri*, *Scleranthus diander*, *Convolvulus erubescens*, *Ptilotus spathulatus* and *Pimelea humilis*. The other is characterised by the following native species: *Gnaphalium collinum*, *Hypericum gramineum*, *Ehrharta stipoides* and *Drosera peltata*.

TABLE 2

Sorted table for quadrats with *Carex tasmanica*

```
                                1223112112 123433333    1 23 1 12331222
                                5145275036569004678979469302142831312788
Lomandra longifolia             111--------------11------------1-------
*Acetosella vulgaris            11----------1---1-1----------------1---
*Aphanes arvensis               -1-----------------1--------------------
*Trifolium pratense             -11-----------1----1--------------------
*Poa pratensis                  1-1--------------1-1--------------------
Hypoxis glabella                -11--1-------------------------------------
*Bromus mollis                  111-----------------------------------------
*Briza minor                    -1--1---------------------------------------
Mazus pumilio                   --1--1--------------------------------------
*Bromus diandrus                11-1-------1--------------------------------
*Rumex crispus                  1------------11--1-1--------------------
*Phalaris spp.                  -------------1----1--------------------
*Carduus nutans                 ------------1---1----------------------
Ehrharta stipoides              -1--1-------1--------------------------
*Lolium perenne                 1-11-11-11-1--1--11---------------------
Elymus scabrus                  ----1-----11---------------------------
Carex gaudichaudiana            -----1----11---------------------------
*Trifolium glomeratum           ----1----1-1---------------------------
Juncus bufonius                 ----1-----1----------------------------
+Schoenus absconditus           -----1-1-111---------------------------
Asperula conferta               -------1-111----1--1--------------------
Geranium solanderi              -------111-1---11-11--------------------
*Myosotis discolor              -----------1-------1--------------------
Veronica gracilis               -----1-111-1---11----------------------1
*Cirsium vulgare                1-11--111111-1-111--1-------1-----------
*Bellis perennis                ----------11-------1-------1------------
*Trifolium dubium               -1---1-111-111-----1-----------1-1-1---
*Taraxacum officinale           -----111-1-----------------------------1-
Poa labillardierei              111-11-11111---111-1-111111--1--1-------
*Aira caryophyllea              -1--11----------------------------------1
Acaena novae-zelandiae          11--1--1111111-1111---1-----1---1-------
*Prunella vulgaris              ----1-------1--------------------1------
Juncus australis                ----1-------11-11--------------------11-
*Plantago coronopus             -1-111-1-1111-1-----11-----------11-1--
Epilobium billardierianum       -------1-1----------1-----------------
Carex breviculmis               -1-----1-11-------------------------1-1-1
Calocephalus lacteus            ---------1---------------------------1--
Juncus subsecundus              --------1-----------------------------1
*Trifolium repens               --------1-1---------1-----------1------
Acaena agnipila                 ----------1----------1-----------------
Leptorynchos squamatus          -1--------1----------------------------1
Oxalis perennans                -1--1--1------------1------1-----------
*Hypochoeris radicata           -111--11-1--11-1111111111--11-----1-1--1
Eryngium vesiculosum            --1-----------------------------------1
```

```
                                1223112112 123433333    1 23 1 12331222
                                5145275036569004678979469302142831312788
Oreomyrrhis eriopoda            ----------------1--------------------1
*Anthoxanthum odoratum          1----1-------------1--1----------------
Danthonia carphoides            -1-------------------------1----------
*Trifolium subterraneum         -1-----------------------------------1---
*Vicia sativa                   1-------------1-------11---------------
*Cirsium arvense                ------------------1----------1---------
*Cynosurus cristatus            ----1----------------------------1------
Carex tasmanica                 11111111111111111111111111111111111111
Juncus spp.                     1-111--1111111111----1111111-1111-1-1111
*Holcus lanatus                 1-1-11-111111--1111-11111111111111-11111
*Plantago lanceolata            1---1111--1111-11-1-111111111-1111111111
Danthonia spp.                  -1--11----1-1-------1--1111-11---------1
Acaena echinata                 -----------11-----1-11------------1----1
*Leontodon taraxacoides         --1-1--1-111111-----11111---11--111----1
Eleocharis acuta                -----1--------11-------1-----111--------
Leptospermum lanigerum          ---------1----------------------1--1-1--
Hypericum gramineum             --------1------------------------111-1--
Carex gunniana                  -------111-11------11-111-1----111-1-1--
*Rosa rubiginosa                ----1--------1---1----1-------11-1-111--
*Potentilla spp.                -------------1-------------1----1-------
*Sonchus asper                  ----------------1--1--------11-----1111-
*Anagallis arvensis             ------------1----------11-------11------
*Ulex europaeus                 ---1-1-----------111-------1--1-1--
*Dactylis glomerata             -------------1---11-1111------1--1--11--
*Agrostis capillaris            ----1---1-11--11-1--11111-------1111111-
Themeda triandra                -11------------------1-11111------1----1
Schoenus apogon                 --1-11--1-----------1-11111-1-----1-----
*Centaurium erythraea           ----1---------------1-1-----------------
*Tragopogon porrifolius         1--1-----------------1--------11--------
*Picris hieracioides            -------------1------1--1----1-1---------
Plantago varia                  ------1---------------------1----------1
Danthonia caespitosa            ----------1--------------11-------------
Danthonia laevis                ----1---------------1-----------------1
*Juncus articulatus             ---1------1---1--------11-1---11-------1
*Dipsacus fullonum              -------------------------11-----1-11-1--
Dichondra repens                ---------------------------------1------1
*Rubus fruticosus               ------------------------111111----1-1-1--
Poranthera microphylla          ----------------------------11-----------
*Urospermum dalechampii         -------------------------------11--------
*Avena fatua                    ------------------------11-1----------
*Crataegus monogyna             ------------------------11-1-----1-----
Juncus pauciflorus              1-----------------------11--111--------
Eleocharis sphacelata           ----------------------------1----------
*Foeniculum vulgare             ------------------------11-1-11--------
Ajuga australis                 --------------------1-1-----------------
Danthonia racemosa              ----------------------11----------------
*Sonchus oleraceus              ----------------------11----------------
*Lolium rigidum                 ----------------------11----------------
Agrostis avenacea               ----------------------11--------------1
*Lotus corniculatus             --------------------1-----------------1
```

Additional species
15: **Cerastium glomeratum, *Phalaris canariensis*
21: *Colobanthus curtiseae, Crassula sieberiana, Chrysocephalum apiculatum, *Erophila verna, Hovea linearis, *Parentucellia viscosa, Pimelea humilis, Scleranthus biflorus*
24: *Bolboschoenus caldwellii, Cotula australis, Glyceria australis, Hypoxis hygrometrica, Ranunculus decurvus, Senecio hispidulus, Villarsia reniformis*
35: **Erodium cicutarium, *Lepidium africa hnum, *Poa bulbosa*
12: *Rumex dumosus, Solenogyne gunnii*
17: *Acaena ovina, Danthonia semiannularis, Drosera peltata, Plantago antarctica*
25: **Briza maxima, *Eragrostis sp., *Trifolium fragiferum*

*** = introduced species**
+ = endemic species

13: *Carex appressa, Carex inversa*
26: *Drosera pygmaea*
16: **Plantago major*
29: *Dichelachne rara, Hydrocotyle sibthorpioides*
30: *Epilobium hirtigerum*
40: **Lysimachia nummularia*
34: **Potentilla spp., *Rumex pulcher*
36: **Capsella bursa-pastoris, Plantago paradoxa*
37: **Cynosurus echinatus*
38: **Achillea spp., Hemarthria uncinata*
39: **Moenchia erecta, *Ranunculus repens*
7: **Linum trigynum*
9: *Astroloma humifusum, Eucalyptus ovata, Geranium potentilloides, Juncus planifolius, Linum marginale*
4: **Erica lusitanica, Eriochilus cucullatus, Eucalyptus globulus, Leptospermum scoparium, *Leucanthemum vulgare*
6: *Stipa spp.*
19: *Baumea acuta, Isolepis platycarpus*
14: *Danthon gia penicillata*
23: **Salix alba, Gonocarpus tetragynus*
22: *Rumex brownii*
28: **Juncus capitatus, *Paspalum dilatatum*
8: *Carex iynx, Centipeda minima, Cotula reptans, Geranium sessiliflorum, Hypericum japonicum, Plantago daltoni*

The latter community occurs in areas of higher available moisture than the former, which is the characteristic community of the driest sites on nutrient-rich soils in the state.

Responses of the Species to Different Management Regimes

Both species can respond favourably to mechanical disturbance. Many of the *C. tasmanica* populations grow in drainage ditches, and young plants are usually associated with bare ground. *S. absconditus* attained its highest measured density on an old lateritic gravel pit (mean = 305 per m^2, standard error = 32). *S. absconditus* is also tolerant of mowing and the scraping of the topsoil (A. North, pers. comm.).

Neither species appeared to be disadvantaged by sheep grazing, although *C. tasmanica* does not respond well to cattle grazing, being absent across fencelines where cattle are grazed. The relative densities per m^2 of *S. absconditus* in ungrazed (mean = 124, standard error = 24), lightly grazed (mean = 169, standard error = 23) and heavily grazed (mean = 188, standard error = 39) native pastures indicate that this species may be favoured by grazing, presumably as a result of competition reduction (cf. Gilfedder & Kirkpatrick 1994). The density of *S. absconditus* varies significantly with either grass cover, being highest at medium levels; bare ground, being highest at medium levels and absent where bare ground is absent; rock cover, being greatest at high and low levels; or litter, being highest at low levels (table 4).

Carex tasmanica also occurs at sites where herbicide has been used to control roadside vegetation. Where most species have died, it maintains its health.

Pine bark mulching was the most successful of the treatments for the establishment of new germinates (table 5). Mowing appeared to preclude such establishment (table 5). The three treatments resulted in no statistically significant changes in percentage cover, number of clumps or number of individuals over the four-year period. There was an unsurprising significant increase in grass, exotic herb and exotic rosette cover in the four years after the burning and herbiciding treatment, but the levels of cover were not as great as those resulting from the mowing treatment. Exotic grass cover also significantly increased over the four years in the woodchip mulch and mown treatments (table 5).

Conservation and Management

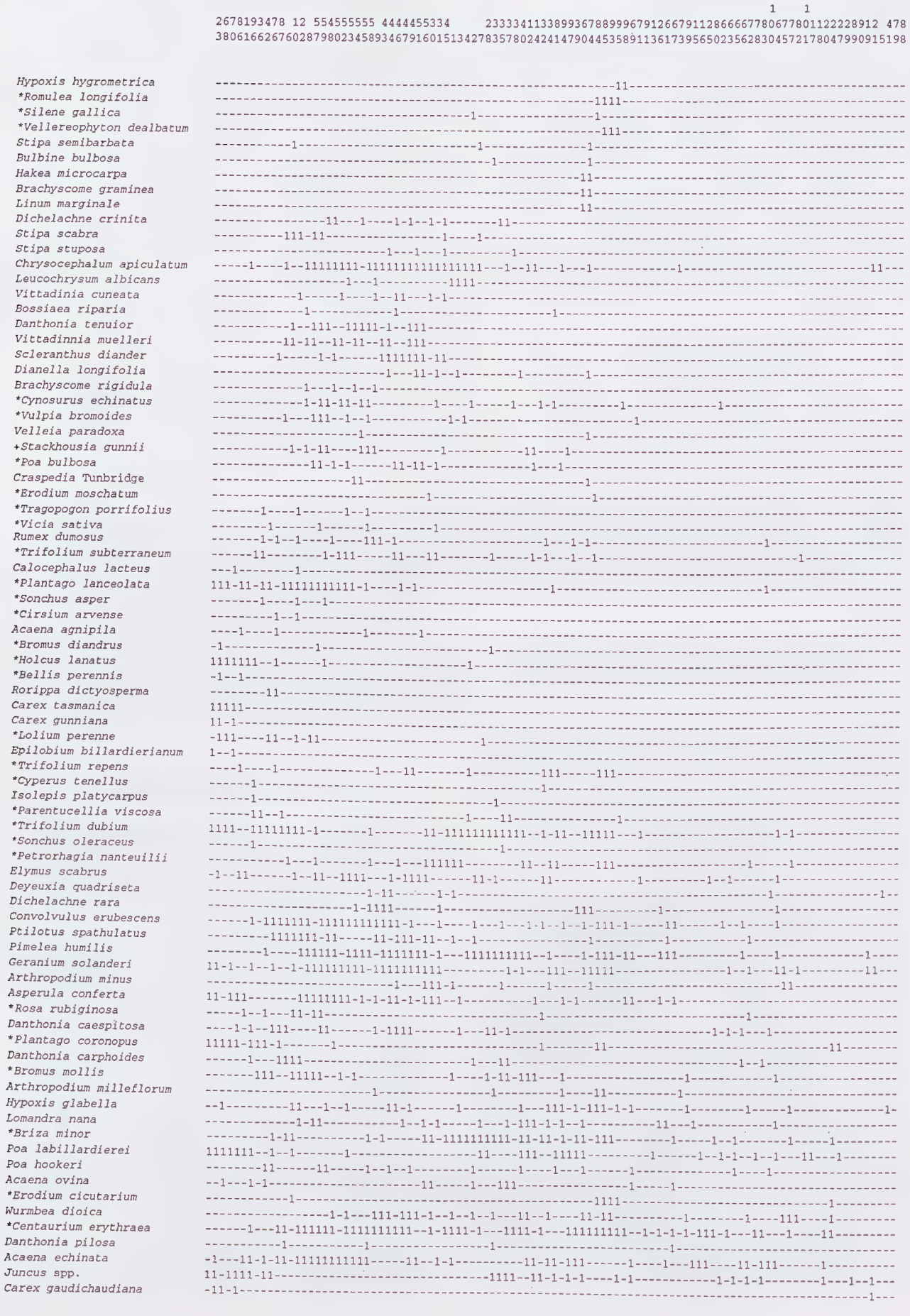
We located many previously unknown populations of both *C. tasmanica* and *S. absconditus* between 1991 and 1995. *S. absconditus* proved to be extremely common in native pastures. It is found in two secure reserves (Township Lagoon Nature Reserve and Tom Gibson Nature Reserve), and in several less secure reserves, such as the Meehan Range State Recreation Area and the Queens Domain in Hobart. This security, its large number of known populations and its ability to persist with current land use, short of cultivation, has resulted in its removal from the national listing of threatened species (Endangered Flora Network 1993) and the Tasmanian state listing (Flora Advisory Committee 1994).

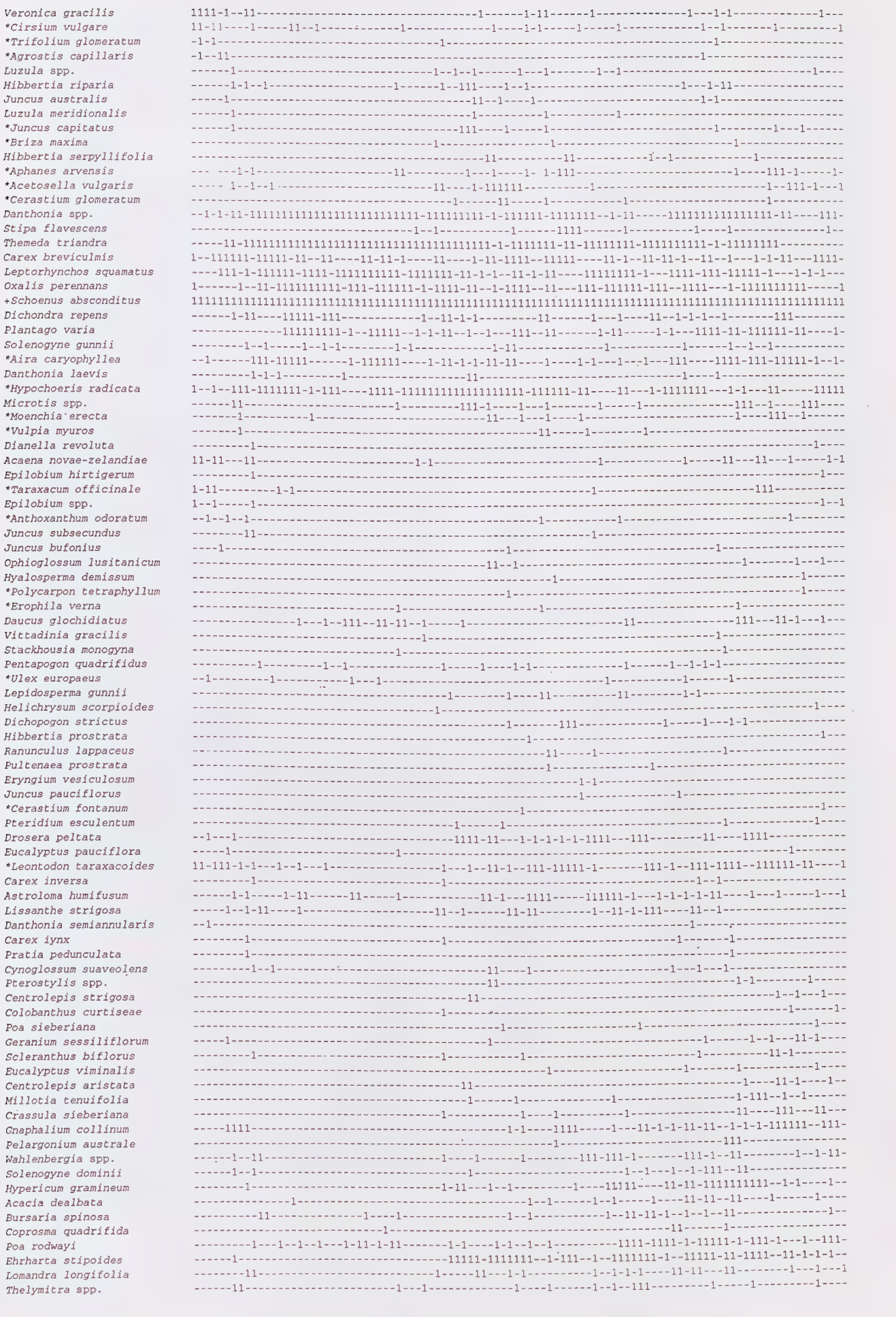
The majority of the populations of *C. tasmanica* are on either private land or on road or rail reserves. It occurs in a number of council reserves, such as the Queens Domain in Hobart. Two individuals were recorded from a picnic area at Myrtle Gully within the Mount Wellington Park, which has secure status. Another slightly larger population occurs within the less secure Lake Dulverton Wildlife Sanctuary.

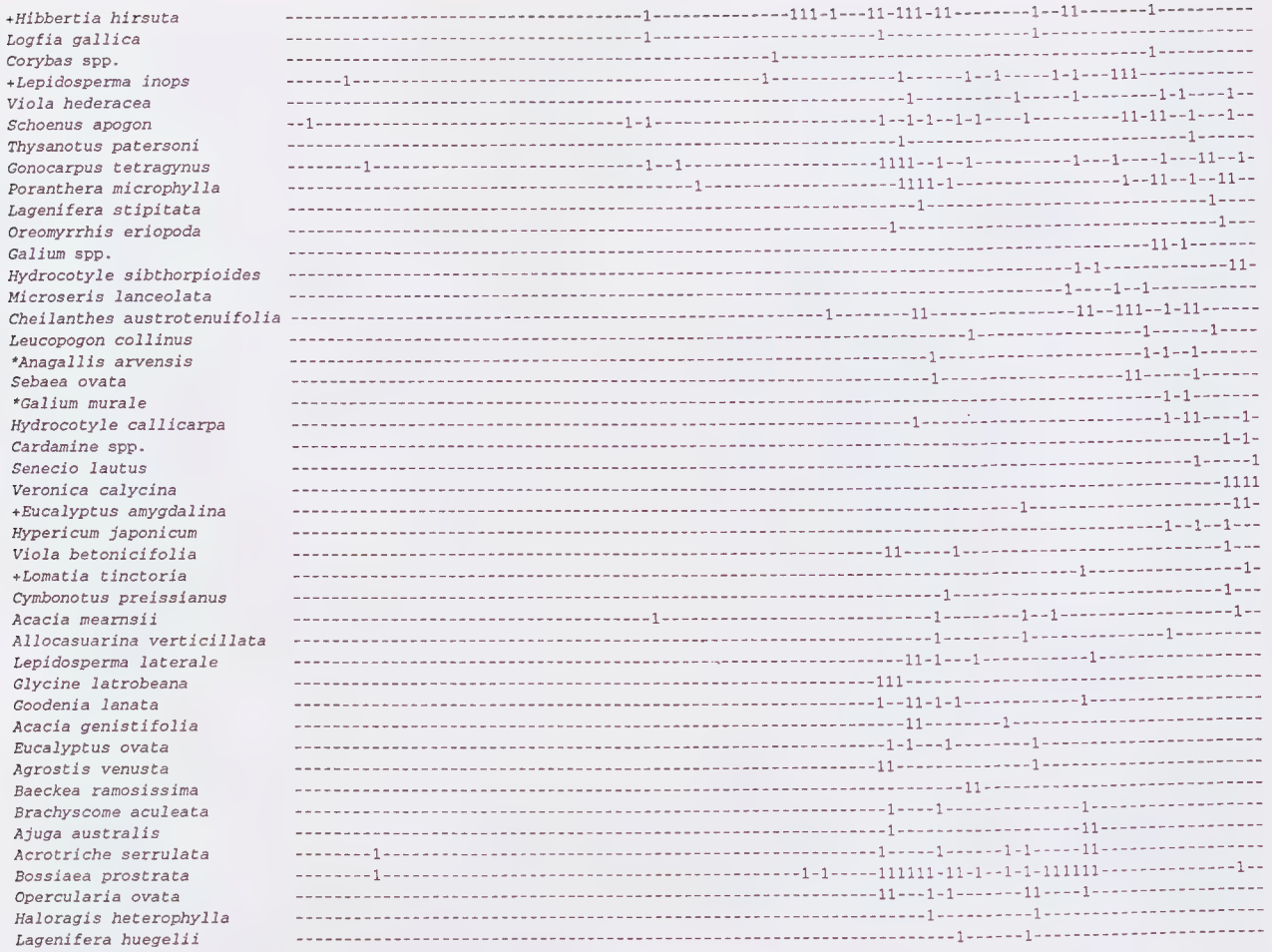
Although many new populations of *C. tasmanica* have been found, its future is not considered secure. Virtually all populations are found on private land or roadside verges,

TABLE 3

Sorted table for quadrats with *Schoenus absconditus*




Veronica gracilis
*Cirsium vulgare
*Trifolium glomeratum
*Agrostis capillaris
Luzula spp.
Hibbertia riparia
Juncus australis
Luzula meridionalis
*Juncus capitatus
*Briza maxima
Hibbertia serpyllifolia
*Aphanes arvensis
*Acetosella vulgaris
*Cerastium glomeratum
Danthonia spp.
Stipa flavescens
Themeda triandra
Carex breviculmis
Leptorhynchos squamatus
Oxalis perennans
+Schoenus absconditus
Dichondra repens
Plantago varia
Solenogyne gunnii
*Aira caryophyllea
Danthonia laevis
*Hypochoeris radicata
Microtis spp.
*Moenchia erecta
*Vulpia myuros
Dianella revoluta
Acaena novae-zelandiae
Epilobium hirtigerum
*Taraxacum officinale
Epilobium spp.
*Anthoxanthum odoratum
Juncus subsecundus
Juncus bufonius
Ophioglossum lusitanicum
Hyalosperma demissum
*Polycarpon tetraphyllum
*Erophila verna
Daucus glochidiatus
Vittadinia gracilis
Stackhousia monogyna
Pentapogon quadrifidus
*Ulex europaeus
Lepidosperma gunnii
Helichrysum scorpioides
Dichopogon strictus
Hibbertia prostrata
Ranunculus lappaceus
Pultenaea prostrata
Eryngium vesiculosum
Juncus pauciflorus
*Cerastium fontanum
Pteridium esculentum
Drosera peltata
Eucalyptus pauciflora
*Leontodon taraxacoides
Carex inversa
Astroloma humifusum
Lissanthe strigosa
Danthonia semiannularis
Carex iynx
Pratia pedunculata
Cynoglossum suaveolens
Pterostylis spp.
Centrolepis strigosa
Colobanthus curtiseae
Poa sieberiana
Geranium sessiliflorum
Scleranthus biflorus
Eucalyptus viminalis
Centrolepis aristata
Millotia tenuifolia
Crassula sieberiana
Gnaphalium collinum
Pelargonium australe
Wahlenbergia spp.
Solenogyne dominii
Hypericum gramineum
Acacia dealbata
Bursaria spinosa
Coprosma quadrifida
Poa rodwayi
Ehrharta stipoides
Lomandra longifolia
Thelymitra spp.



Additional species

68: **Plantago major* 70: *Eleocharis acuta, Mazus pumilio, Plantago antarctica* 86: *Drosera pygmaea, Leptospermum lanigerum* 11: **Juncus articulatus* 196: **Dactylis glomerata* 42: *Senecio quadridentatus* 76: *Calochilus herbaceus, Villarsia reniformis* 87: **Trifolium pratense* 10: *Ranunculus scapigerus* 22: **Rumex crispus* 59: **Cardaria draba, *Poa pratensis* 48: *Daviesia ulicifolia* 52: *Trachymene humilis* 49: **Crataegus monogyna* 30: **Conyza albida, Isoetopsis graminifolia, *Passiflora cinnabarina* 45: *Chrysocephalum semipapposum* 7: *Stipa mollis* 28: **Bromus hordeaceus* 33: *Bulbine glauca, Luzula flaccida* 40: *Bossiaea cinerea* 12: *Pterostylis cynocephala* 14: **Arctotheca calendula, Pterostylis cucullata* 34: *Comesperma volubile, Senecio glomeratus* 60: *Banksia marginata, Chrysocephalum aff.apiculatum* 74: *Microtis unifolia, Stipa pubinodis* 84: *Rubus parvifolius* 85: *Wurmbea uniflora* 98: *Imperata cylindrica* 71: *Burchardia umbellata, Juncus procerus, Tetratheca procumbens* 91: *Cotula reptans, *Erodium botrys* 13: *+Epacris tasmanica, +Eucalyptus pulchella, Leptospermum scoparium* 26: *+Bedfordia salicina, +Cyathodes pendulosa, Notelaea ligustrina* 61: *Lythrum hyssopifolium* 67: *Danthonia racemosa* 16: *Epacris gunnii, Grevillea australis, Melaleuca gibbosa, Pomaderris pilifera, +Spyridium microphyllum, Styphelia adscendens* 80: *Pultenaea pedunculata* 62: **Linum trigynum* 65: *Eriochilus cucullatus* 66: *Juncus filicaulis* 72: *+Clematis gentianoides* 83: *+Melaleuca pustulata* 100: *Danthonia setacea, *Reseda luteola* 64: *Agrostis aemula, Asplenium flabellifolium, Epacris impressa* 75: **Cynosurus cristatus* 82: *Diuris sulphurea, Hydrocotyle callicarpa* 101: *+Ozothamnus scutellifolius* 20: *Cryptandra amara, Stylidium graminifolium* 27: *Ozothamnus ferrugineus* 89: *Aphelia pumilio, Calandrinia calyptrata, *Cicendia filiformis, *Sagina apetala* 21: *Amperea xiphoclada, +Eucalyptus tenuiramis, Hovea linearis* 5: *Acianthus spp., Brachyloma ciliatum, Cotula australis, Gonocarpus micranthus, Hydrocotyle hirta, *Sagina procumbens* 41: *Ehrharta distichophylla, Eucalyptus globulus, Olearia phlogopappa, Olearia ramulosa, Pomaderris elliptica* 79: *Agrostis parviflora, Baeckea gunniana, Cotula alpina, *Verbascum thapsus, Viola cleistogamoides* 88: *Hymenanthera dentata*

* = introduced species, + = Tasmanian endemic species

TABLE 4
Mean densities of *Schoenus absconditus** in varying cover classes

Type of cover	Cover class†							H‡
	0	1	2	3	4	5	6	
grass	–	332	170	182	92	–	185	12.14 §
herb	–	–	287	152	215	–	–	7.88
exotics	83	196	195	220	–	–	–	4.91
bare ground	–	159	220	262	238	184	95	21.19 ¶
rock	163	84	–	–	–	395	237	21.44 ¶
litter	193	141	313	262	–	123	–	11.50 §

* Mean densities per square metre (Mueller-Dombois & Ellenberg 1974)
† 0 = 0%, 1 = 1%, 2 = 2–5%, 3 = 6–25%, 4 = 26–50%, 5 = 51–75%, 6 = 76–100%
‡ H values and significance levels for the Kruskal-Wallis One-Way Analysis of Variance by Ranks (§ = P<0.05, ¶ = P<0.001)

and generally consist of less than 100 individuals, making them highly vulnerable to localised extinction through the inadvertent or deliberate use of a plough or grader. Such an extinction occurred in the municipality of Kingborough in the course of road preparation for a subdivision. During the last five years, two populations have become extinct. This is a loss of more than 10% of the known populations every decade — a rate which could lead to the endangerment or extinction of the species within 50 years. The species is best considered to be vulnerable to extinction and should be reinstated to the state list of threatened flora (Flora Advisory Committee 1994).

Carex tasmanica does not place high demands on managers (Gilfedder 1991). The avoidance of deep scraping, cattle grazing and mowing, and the maintenance of the other forms of disturbance currently employed are all that is required. It would be highly desirable to ensure that at least one large population was within a secure reserve. Areas that might be suitable for secure reservation include city parks and some private land. There are areas of private grassland with this species that, if purchased and maintained under present management regimes, would also increase the security of lowland temperate grassland and other rare and threatened species (Kirkpatrick 1994).

ACKNOWLEDGEMENTS

Alex Buchanan, Stephen Harris, Mark Neyland, Andy North and Andrew Zacharek provided some site records for *C. tasmanica*. Dr Winifred Curtis provided taxonomic assistance. Dennis Morris and Alex Buchanan helped with species identification. The Hobart City Council, and in particular John Rankin, co-operated with experiments on the Queens Domain. Gian Walthur helped with some data collection. Dr G. van der Geer drew some of the figures.

This project was supported by grants from the Worldwide Fund for Nature (Australia) and the Endangered Species Program of the Australian Nature Conservation Agency (ANCA).

TABLE 5
Mean and standard error of *Carex tasmanica* and other lifeform groups under different management regimes*

	1991†	1995†
***Carex tasmanica* individuals/m²**		
woodchips	137.6 ± 37.8	156.3 ± 39.2
spray/burn	96.9 ± 33.9	350.0 ± 110.0
mown	92.5 ± 28.1	147.5 ± 41.7
***Carex tasmanica* clumps/m²**		
woodchips	8.73 ± 1.91	16.85 ± 2.96
spray/burn	10.27 ± 3.56	9.82 ± 2.83
mown	19.38 ± 4.61	18.13 ± 4.61
***Carex tasmanica* germinates/m²**		
woodchips	15.62 ± 9.60	6.87 ± 4.41
spray/burn	4.91 ± 3.35	3.12 ± 1.43
mown	0	0
***Carex tasmanica* percentage cover**		
woodchips	6.70 ± 1.65	5.90 ± 1.42
spray/burn	4.71 ± 1.56	8.96 ± 2.67
mown	2.60 ± 1.09	5.30 ± 0.92
Percentage cover of exotic herbs		
woodchips	11.00 ± 2.73	17.40 ± 4.04
spray/burn	6.43 ± 1.25	11.71 ± 2.04 ¶
mown	31.20 ± 3.52	31.50 ± 3.49
Percentage cover of exotic rosette herbs		
woodchips	3.60 ± 1.82	5.70 ± 2.59
spray/burn	3.14 ± 0.71	7.86 ± 1.12 §
mown	22.80 ± 2.00	27.80 ± 2.72
Percentage cover of exotic grasses		
woodchips	18.20 ± 2.33	33.80 ± 5.47 ‡
spray/burn	10.04 ± 3.28	29.79 ± 4.94 §
mown	24.56 ± 3.66	36.53 ± 3.22 §

* Density, cover and number of germinants, and herb, rosette herb and exotic grass cover per square metre.
† Significance levels shown for the Mann-Whitney U Test (‡ = P<0.05, § = P<0.01, ¶ = P<0.001).

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ELAEOCARPUS (ELAEOCARPACEAE) ENDOCARPS FROM THE OLIGO–MIOCENE OF EASTERN AUSTRALIA

by Andrew C. Rozefelds and D.C. Christophel

(with two tables, two text-figures and three plates)

Rozefelds, A.C. & Christophel, D.C., 1996 (30:vi): *Elaeocarpus* (Elaeocarpaceae) endocarps from the Oligo-Miocene of Eastern Australia. *Pap. Proc. R. Soc. Tasm.* 130(1): 41–48. ISSN 0080–4703. Tasmanian Herbarium, GPO Box 252C Hobart, Tasmania, Australia 7001 (ACR); Botany Department, University of Adelaide, PO Box 496, Adelaide, South Australia 5005 (DCC).

Elaeocarpus peterii sp nov. is described from the Oligo-Miocene Glencoe locality in central Queensland. This species has prominent stellate ridges and fine punctate ornamentation. These features support a close relationship to extant *E. stellaris* L.S. Smith from northeastern Queensland. *Elaeocarpus clarkei* (F. Muell.) Selling is redescribed. The punctate ornamentation and large oval endocarps of *E. clarkei* (F. Muell.) are closely comparable to extant *E. bancroftii* F. Muell. & F.M. Bail. and *E. linsmithii* G.P. Guymer from north eastern Queensland. *Elaeocarpus clarkei* is a common element in many Oligo-Miocene deep leads in southeastern Australia. The age of some of the deep leads (buried placer deposits) in Victoria, e.g. Haddon and Foster, is discussed; the limited data available suggests a minimum mid-Miocene age for these localities.

Key Words: ***Elaeocarpus*, Elaeocarpaceae, endocarp, fruits, deep leads, Haddon, Foster, Glencoe, Tertiary, Miocene, Oligocene, Australia.**

INTRODUCTION

Elaeocarpaceae is represented in the Tertiary fossil record in Australia by pollen, leaves and fruits. Fossil records of leaves or pollen have been referred to, or compared with the family generally, and not an extant genus (e.g. Christophel *et al.* 1987, Christophel & Greenwood 1987, Hill & Macphail 1983). In the Elaeocarpaceae, only *Elaeocarpus* L. and *Aceratium* DC. have drupes. The endocarp in *Aceratium* is weakly lignified and has prominent and persistent mesocarp fibres. *Elaeocarpus* endocarps typically have woody and strongly ornamented endocarps and lack persistent mesocarp fibres. *Elaeocarpus* has been recognised as a ubiquitous element of the Tertiary floras of Australia, because the woody endocarps are robust and fossilise readily (Kirchheimer 1935, Selling 1950, Blackburn & Sluiter 1994, Rozefelds 1990a, b, Rozefelds & Christophel 1996).

The affinities of many of the fossil fruits that have been compared with, or referred to *Elaeocarpus* remain poorly studied. *Penteune clarkei* was described by Mueller in 1873 from deep leads (buried placer deposits) in Victoria. Mueller referred this taxon to a new genus, the name alluding to the five valves of the endocarp. He was unsure of its generic and familial affinities but suggested it belonged "most probably to Sapindaceae, although the possibility of its having formed a genus of the Meliaceous order is not excluded" (Mueller 1874: 21). Selling (1950) recognised that *E. clarkei* F. Muell. was similar to extant *E. bancroftii* F. Muell. & F.M. Bail. and referred it to *Elaeocarpus*. A study of extant *Elaeocarpus* species from New Zealand and Australia (Rozefelds 1990b, Rozefelds & Christophel 1996, Rozefelds & Christophel, pers. obs.) shows that endocarp size and ornamentation is highly variable and groups of taxa within *Elaeocarpus* can be identified by endocarp morphology, particularly ornamentation type (Rozefelds & Christophel 1996). The study of endocarp morphology in *Elaeocarpus* supported Selling's suggestion of a relationship between *E. clarkei* and *E. bancroftii*, but also identified similarities with other taxa. In the present paper, endocarp morphology of these taxa is examined in detail. A new taxon, which also has punctate ornamentation, is described from the Glencoe locality, central Queensland. Similarities in endocarp morphology between the fossil taxa and extant *Elaeocarpus* taxa are recognised, and the biogeographical implications of these fossil taxa are discussed. A southern origin for the family is supported and two biogeographical hypotheses are proposed to explain the presence of the genus in the southeast Asian region.

MATERIALS AND METHODS

The early collections of fossil fruits are from deep leads that were mined for gold late last century in Victoria and New South Wales. These fruits were either donated to, or purchased for museum collections. Documentation of these early museum collections is often poor, with limited stratigraphic information and collection details. The type material of most of Mueller's taxa cannot be confidently identified, because the published illustrations do not match the existing specimens, and the original specimens used in illustrations were not identified. Some specimens have also partially disintegrated due to the oxidation of pyritic minerals in the fruits, and other material has decomposed completely. Material studied in this paper is from the Australian Museum (AMF), Museum of Victoria (NMVP), Geological Survey of New South Wales (MMF) and Queensland Museum (QMF).

The preservation of fossil material varies. The majority of *E. clarkei* material examined comes from deep leads in Victoria and New South Wales and the material is preserved as "charcoalified" fruits. *Elaeocarpus clarkei* from Elsmore is preserved as moulds with no internal structures preserved and no original tissue. The Glencoe specimen is silicified and some internal structures are present, although no organic tissue is preserved. Most of the comparative extant material of north Queensland *Elaeocarpus* species was provided by CSIRO, Atherton (QRS). The material examined is listed in table 1.

TABLE 1
List of extant *Elaeocarpus* spp. examined, including locality, collector and source of material

Taxon	Locality	Collector
Elaeocarpus bancroftii F. Muell. & F.M. Bail.	SFR Little Pine L.A eastern Queensland 17°00'S, 145°50'E	Gray 2328 (QRS)
	Noahs Creek and Olivers Creek, Cape Tribulation area, NE Queensland, 16°09'S,145°27'E	ACR collection
E. linsmithii Guymer	Mt Bartle Frere, NE Queensland, 17°23'S, 145°48'E	Hyland 13606 (QRS)
E. stellaris L.S. Smith	Barong L.A. State Forest Reserve, NE Queensland, 17°30'S, 145°47'E	Stocker 1774 (QRS)
	Coles Bay, NE Queensland, 16°09'S, 145°27'E	ACR collection

FIG. 1 — Localities mentioned in text and distribution of extant Elaeocarpus stellaris, E. bancroftii *and* E. linsmithii *in northeastern Queensland arrowed. Localities for* E. clarkei *are marked with a circle while the type locality for* E. peterii *sp. nov. is marked with a square.*

LOCALITIES AND AGE

Elaeocarpus clarkei has been collected from deep leads in Victoria (Haddon 37°36'S, 143°48'E, Eldorado 36°18'S, 146°32'E, and Foster 38°39'S, 146°10'E) and New South Wales (Bathurst 33°24'S, 149°35'E and Orange 33°17'S, 149°05'E). The Boola Boola [~ 38°04'S, 146°20'E] (Victoria) fruits are from bores (fig. 1). There have been numerous estimates of the ages of the Victorian and New South Wales deep leads ranging from Pliocene (Mueller 1874), Miocene (Walcott 1920), late Miocene (Macumber 1978) to Oligocene (Partridge & Wilkinson 1982). Palynological evidence has provided information on the age of some leads, e.g. an Oligocene date for Loddon and Murray Basin leads (Martin 1977, Partridge & Wilkinson 1982, Archer 1984).

While there is no *a priori* reason for assuming that the leads formed contemporaneously, the pulses of sedimentation required for their formation were probably related to periods of uplift, during the Tertiary, of the Eastern Highlands. King (1985), for example, considered that deep leads in the Haddon area were established during the early Tertiary, and initial deposition probably commenced during the Oligocene. There are no published palynological data or radiometric dates, known to the authors, to assist in dating the systematically diverse and historically important Haddon and Foster deep leads in Victoria, where most of the *E. clarkei* specimens recorded in this paper came from.

Elaeocarpus clarkei is recorded from the Orange locality in New South Wales. Radiometric dates of 10.9–12.7 Ma are recorded for basalts that overlie Tertiary sediments in the Orange area and indicate a minimum mid-Miocene age for this flora (Wellman & McDougall 1974). While the systematic and biostratigraphic relationships of the other fruits in these localities have not been critically re-examined, it is suggested, based upon the occurrence of *Elaeocarpus mackayii* (F. Muell.) Kirchheimer, *Rhytidocaryon wilkinsonii* F. Muell., *Spondylostrobus smythii* F. Muell. and *Elaeocarpus clarkei* at Haddon and Orange (Mueller 1874), that these localities are broadly contemporaneous. A minimum mid-Miocene age, possibly Early Miocene age is therefore suggested for the Haddon locality. The age of the other deep leads at Foster, Boola Boola and Eldorado, near Beechworth is unknown. The presence of *E. clarkei* in these localities similarly suggests that these floras are contemporaneous with those at Haddon.

The Elsmore locality (29°47'S, 151°17'E) was referred to by Ettingshausen (1888). Fossil fruits are preserved as steinkerns (moulds). A recent survey of Ettingshausen's localities by Pickett *et al.* (1990) showed that two floras, in lithologically similar sediments (one Miocene in age and the other Oligocene), occur in the Elsmore area. The age of the original material collected is therefore uncertain, although a minimum Miocene age is indicated.

The data available for assessing the age and flora of the Glencoe locality has been discussed previously by Rozefelds (1990a). The silcretes with fossil plants overlie basalts, and a maximum age of 30 Ma for this flora is suggested, based upon radiometric dates for nearby volcanics in this area

(F.L. Sutherland, pers. comm., 1989). An Oligo/Miocene date for the flora is therefore likely.

RESULTS

One group of extant *Elaeocarpus* species, *E. stellaris* L.S. Smith, *E. bancroftii* F. Muell. & F.M. Bail. and *E. linsmithii* Guymer are characterised by a relatively smooth endocarp with punctate ornamentation. The fossil taxa described in this paper also have this punctate ornamentation type. The three extant species also share prominent longitudinal pores in the endocarp wall. *Elaeocarpus stellaris* also has the unique feature of prominent stellate ridges on the endocarp, a feature shared with one of the fossil taxon being described here.

SYSTEMATICS

Family ELAEOCARPACEAE

Elaeocarpus L.

Type Species *Elaeocarpus serratus* L.

Elaeocarpus clarkei (F. Muell.) Selling, 1950: 558
Plate 1A–E, H–K,M.

Basionym: 1873 *Penteune clarkei* F. Muell., p. 1, pl. 7, figs 1–10 (plate 2 herein).
1874 *Penteune clarkei* F. Muell., pp. 20–21, pl. 7, figs 1–10 (republished the 1873 description and figures).
1925 *Penteune clarkei* F. Muell., in Deane (1925), p. 490, pl. 60, figs 1–3.

Neotype (selected here)
AMF9281, Elsmore, New England District, New South Wales (pl. 1A–C).

A neotype is required because the type series figured by Mueller (1873) has not been located in museum collections in Victoria and New South Wales; it is presumed that it has been lost, has decomposed due to pyrites disease or cannot be positively identified from Mueller's original illustrations (pl. 2).

Emended Diagnosis
Elaeocarpus clarkei differs from other *Elaeocarpus* species in the following characters: large, thick, ligneous, usually five partite, rarely four partite endocarps with punctate ornamentation, the absence of persistent mesophyll fibres, and seedless locules compressed by growth of neighbouring seed.

Description
Ligneous endocarps, indehiscent, five partite, rarely four, ovoid to broadly ellipsoid, 25.4–40.5 mm long, 20.1–33.7 mm wide; variable in shape and size; apex rounded, sutures recessed or confluent with endocarp surface; base rounded in outline, blunt or slightly pointed; Walls woody, up to 4.3–7.2 mm thick; surface irregular to moderately irregular, sometimes with a slight mid-sutural ridge down the middle of each section of endocarp; with irregular punctate ornamentation forming thin channels that extend into woody wall of endocarp. Seeds oval in lateral view and seedless locules compressed by development of neighbouring seed.

Material examined
Eldorado Gold Lead, Beechworth district, Victoria, NMVP53911-2, NMVP53917-9; Boola Boola district, Victoria, NMVP166541-3; Haddon district, Ballarat, Victoria, NMVP30586, NMVP53745, NMVP53805, NMVP53813, NMVP53907, NMVP53912, NMVP53915, NMVP53976, NMVP53978; Foster deep leads, Victoria, NMVP199904, NMVP199905; Victory Mine, Homebush Lead, Talbot, Victoria NMVP182177; Orange area, New South Wales, AMF8448; Bathurst, New South Wales, AMF51709; Forest Reefs, Orange, New South Wales, MMF10089-MMF10093, MMF10095.

Remarks
Selling (1950) referred *Penteune clarkei* to *Elaeocarpus* and, while noting the similarity with extant *E. bancroftii*, did not critically compare these two taxa. *Elaeocarpus clarkei* is similar to both extant *E. bancroftii* and *E. linsmithii* in the punctate ornamentation and relatively large, oval, thick, ligneous walled endocarps (pl.. 1). They differ in the number of parts in their fruits. A sample of over 1500 endocarps of *Elaeocarpus bancroftii* from a tree growing in the Cape Tribulation area in northeastern Queensland showed that 95.8% had four partite fruits, 2.6% had three partite fruits, and 1.6% had five partite fruits (Rozefelds, 1990b). *Elaeocarpus clarkei* differs from *E. bancroftii* in that the fruits are typically five partite, rarely four partite (pl..1). *Elaeocarpus linsmithii* is two partite, but as only one specimen of this species was available the infra specific variation is unknown. The base of the endocarp in *E. linsmithii* is acute in outline which differs from the rounded base of *E. clarkei*.

Mueller (1873) interpreted *E. clarkei* as having loculicidal dehiscence. Study of extant and fossil species in *Elaeocarpus* shows that the fruits are indehiscent, although they eventually split along sutures in the fruit. *Elaeocarpus clarkei* also shows evidence of aborted ovules, and usually only one seed develops (pl.. 1M). The endocarps are typically divided by five sutures and are thus derived from a five locular ovary while in *E. bancroftii* the ovary is four-locular (Coode 1984).

Elaeocarpus clarkei is a relatively common taxon in southeastern Australia during the mid-Tertiary, as evidenced by the fossil record. Material figured is from Elsmore, New South Wales (pl.. 1A–C), Bathurst (pl.. 1D, E), Boola Boola, Victoria (pl.. 1H, I), Forest Reefs, Gulgong (pl.. 1J, K) and Haddon (pl.. 1M). The fruits figured from the different localities exhibit morphological variation in the number of depressions and endocarp size and shape (pl. 1; fig. 2). Material from Haddon is often partially degraded. One specimen from Boola Boola (pl.. 1H, I) has a weakly developed ridge (arrowed) down the middle of each part of the endocarp. The variation in size is considerably greater in *E. clarkei* than that recorded for *E. bancroftii* (fig. 2). Additional eroded and partially disintegrated material is known from museum collections but is difficult to refer to this taxon because the surface ornamentation is not always preserved. Transverse sections of these endocarps, however, show the thin channels that perforate the endocarp wall. NMVP53811 is tentatively compared to *E. clarkei* but differs from most of the other material in that the apex is not rounded but obcordate in outline. Mueller (1873: 1) also notes that "an externally very similar fossil has been discovered in Tasmania by Morton Alport [sic], Esq., at Gerlston-Bay [sic, for Geilston] in Tertiary travertin". The whereabouts of this specimen remains unknown.

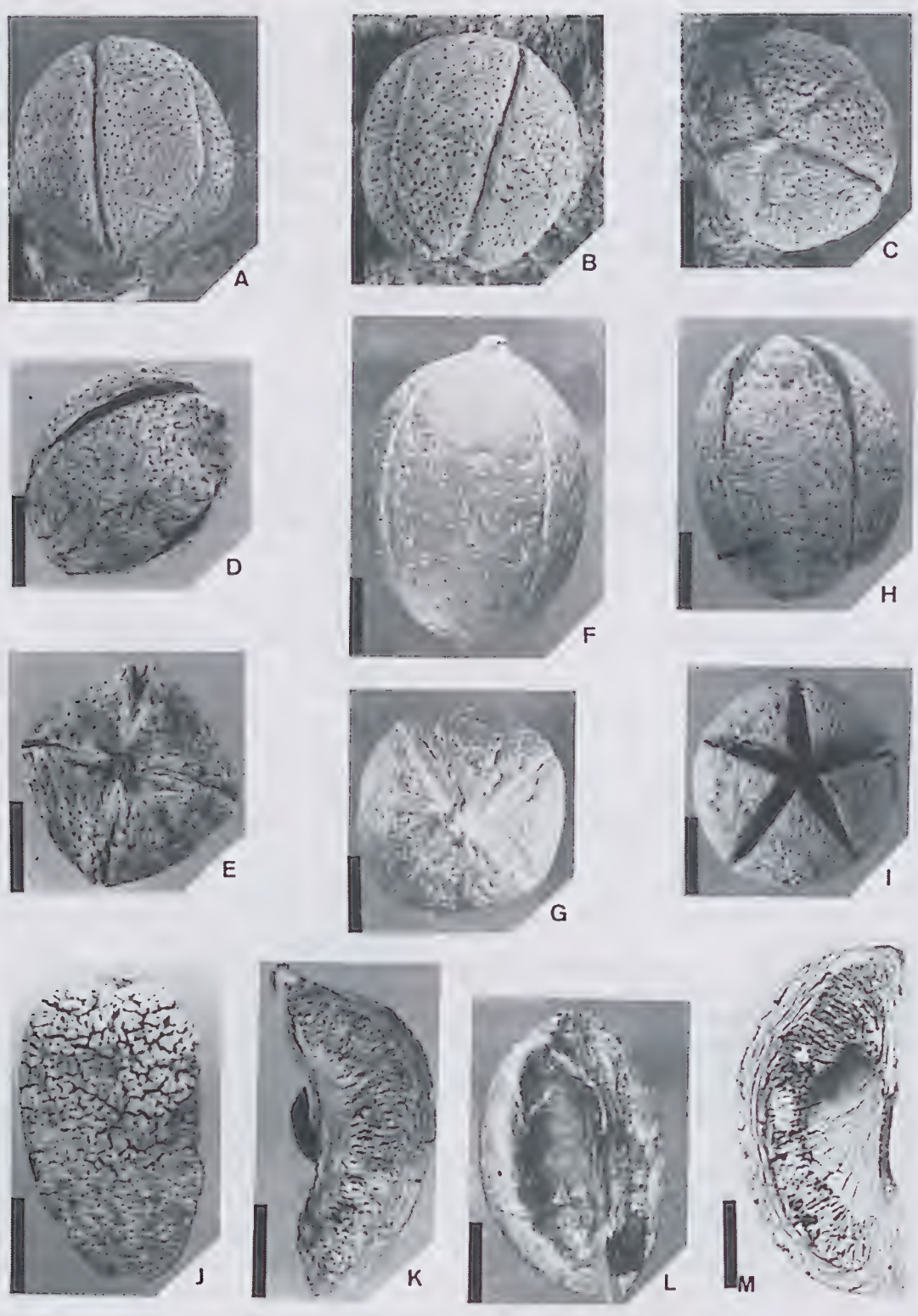

PLATE 1

Fossil Elaeocarpus clarkei *and extant* E. bancroftii *endocarps.*
(A–C) Latex cast of E. clarkei *mould from Elsmore, New South Wales (AMF9281). (A) showing apex; (B) lateral view and (C) basal view. (D–E)* E. clarkei, *four partite fruit from Bathurst, New South Wales (AMF51709). (D) lateral view and (E) apical view. (F–G)* E. bancroftii*: (F) lateral view; (G) apical view (ex QRS, Gray, 2328). (H–I)* E. clarkei *from Boola Boola, Victoria (NMVP166542). (H) lateral view, arrow indicates weakly developed ridge; (I) apical view. (J–K)* E. clarkei *from Forest Reefs, Gulgong, New South Wales (MMF10089). (J) lateral view of a section of endocarp, showing fracturing in fruit wall, although the regular punctate depressions are still evident; (K) internal view of endocarp wall. (L)* E. bancroftii *from Noahs Creek area, northeast Queensland. (M)* E. clarkei *from Smythes Creek, Haddon, Victoria; internal view of section of endocarp showing seed cavity. Scale bars = 10 mm.*

Elaeocarpus peterii Rozefelds & Christophel sp. nov.

Plate 3A, C, E, G, I.

Holotype
QMF18088.

Type Locality
Glencoe Station, Central Queensland, 23°6'S, 148°10'E.

Etymology
Named after the collector, Peter Spackman from Glencoe Station, who kindly made the only known specimen available for study and sectioning. The family name, Spackman, is not used because a taxon *E. spackmaniorum* Rozefelds has been previously described from this locality.

Diagnosis
Elaeocarpus peterii differs from other species of *Elaeocarpus* by the combination of strongly woody endocarps, non-persistent mesophyll fibres, fine punctate ornamentation of the endocarp and prominent lateral flanges that become less pronounced near the base.

Description
Endocarp, large, maximum diameter 27.5 × 23.2 mm long, six partite, apex broadly rounded in outline with prominent circular stalk attachment scar, with base broadly acute. Prominent lateral flanges that extend down endocarp becoming less pronounced near base, flanges 6.7–8.1 mm wide and slightly variable in size, with sutures extending along their length, area between flanges U-shaped, shallowing near base of endocarp. Surface generally smooth with small irregular ridges between the flanges at apex, and irregularly distributed fine depressions. Transverse section shows rare canals.

Material
Only the holotype is known from Glencoe Station, near Capella, central Queensland.

Remarks
The prominent flanged endocarp, sutures along flanges and generally smooth endocarp wall, with fine depressions, strongly suggest affinities with the extant northeastern Queensland species *Elaeocarpus stellaris* (pl. 3). The species differ, as *E. stellaris* has prominent flanges with distinct U-shaped depressions between flanges that extend the entire length of the endocarp (pl. 3B, D, F), whereas in *E. peterii*, the flanges taper towards the base (pl. 3A, C, E, G). *Elaeocarpus stellaris* typically has a five partite fruit (Coode 1984), although seven partite fruits also occur. The significance, if any, of a six partite fruit in *E. peterii* is difficult to assess. The central region of the endocarp in *E. peterii* is hollow, and replacement of internal endocarp structure has not occurred (pl. 3I). In *E. stellaris*, aborted locules occur, but the condition in *E. peterii* is unknown since the central region of the fruit is not preserved.

PLATE 2
Reproduction of Mueller's (1874) original figure of Penteune clarkei. *Scale bar = 10 mm.*

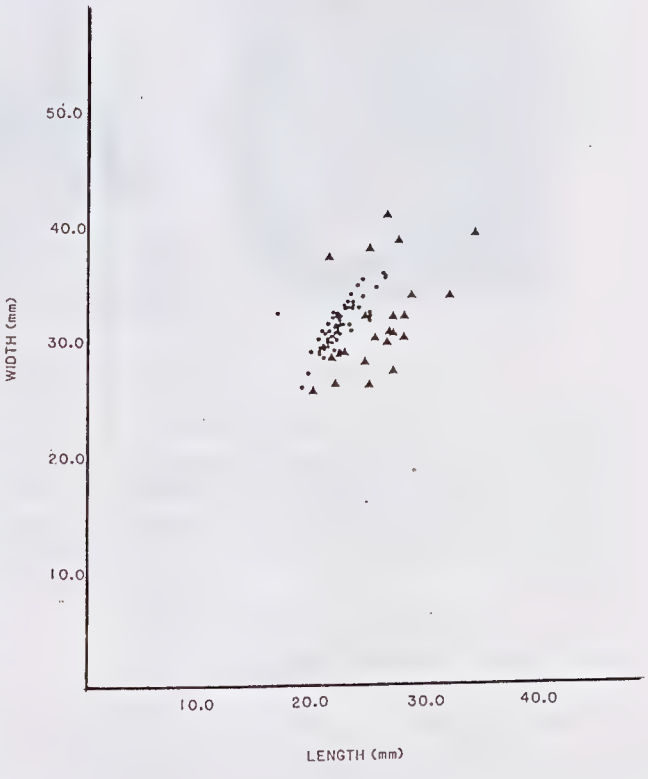

FIG. 2 — Variation in length and width of Elaeocarpus clarkei *(triangles) and* E. bancroftii *(circles) endocarps.*

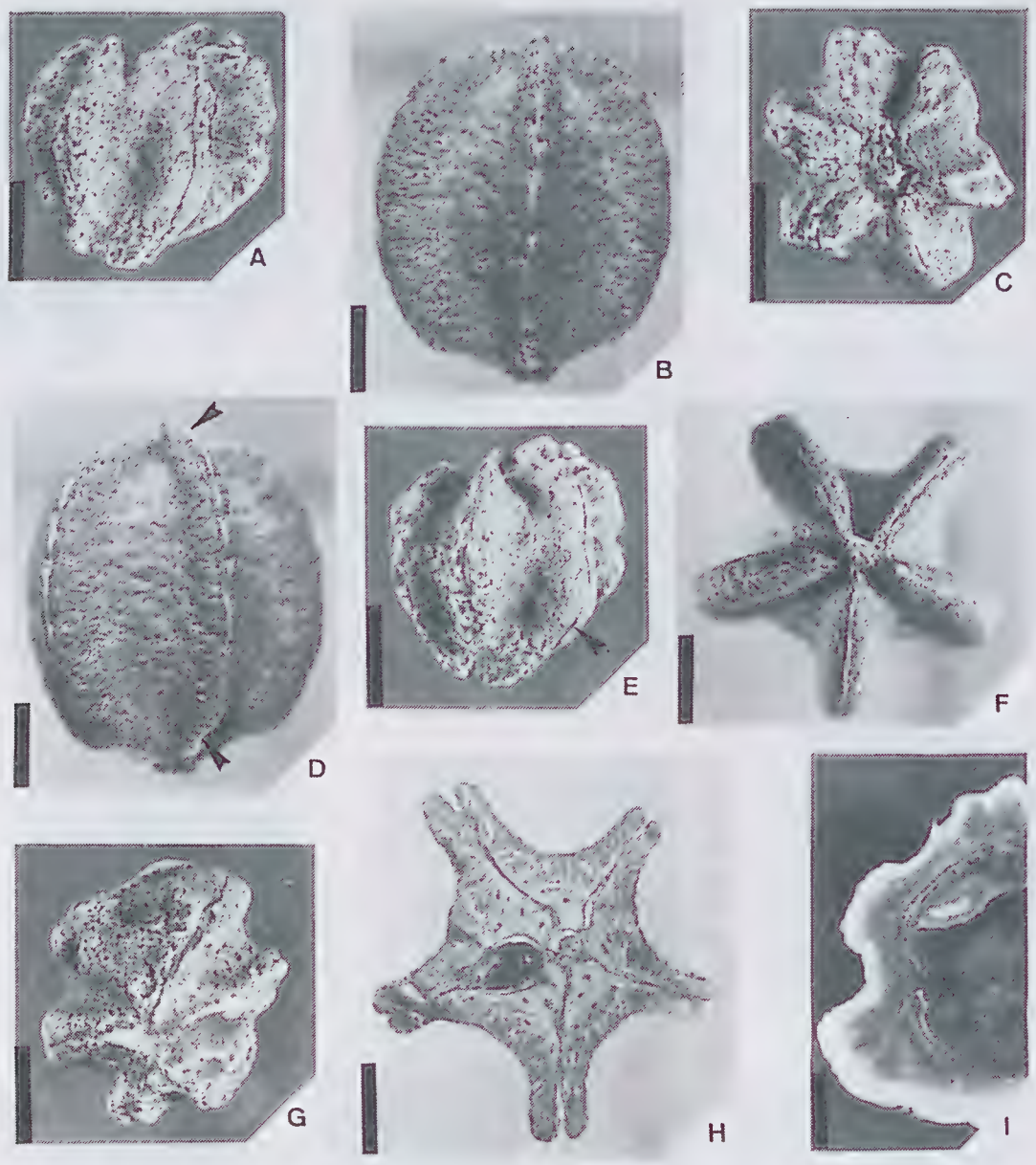

PLATE 3

Fossil Elaeocarpus peterii *sp. nov. and extant* E. stellaris *endocarps.*
(A, C, E, G, I) Holotype of E. peterii *from the Glencoe locality, central Queensland (QMF18088). (A, E) various lateral views, arrow indicates suture along flanges; (C) apical view; (G) basal view; (I) section through endocarp, shows a quartz-lined cavity and much of the inner portion of the endocarp is not preserved. (B, D, F, H)* Elaeocarpus stellaris *from Coles Bay area, northeastern Queensland (ex QRS, Stocker 1774). (B, D) lateral views, arrows indicate sutures along flanges; (F) apical view;* E. stellaris, *from author's (ACR) collection; (H) transverse section. Scale bars = 10 mm.*

DISCUSSION

Elaeocarpaceae is generally considered to be Gondwanic in origin based upon the essentially southern distribution of many modern genera (Raven & Axelrod 1972, 1974). The abundant Eocene leaf megafossil record (Turnbull 1986, Christophel & Greenwood 1987, Christophel *et al.* 1987) in southern Australia indicates the family was widespread during the Early Tertiary. Fossil wood referred to the Elaeocarpaceae, from the Tertiary of India and the Paleocene of Patagonia, also attests to a southern origin for this family (Prakash & Dayal 1964, Petriella 1972). Tertiary fruits from the London Clay Floras, England, have been referred to *Sloanea* (as *Echinocarpus)* but their placement within the genus has been questioned by Coode (1984).

The genus *Elaeocarpus* is widespread in the Indo-Pacific region from India, through Indo-China, Philippines, Indonesia to New Guinea and the Solomon Islands. It has disjunct outliers in Madagascar, New Caledonia, New Zealand and Hawaii (Raven & Axelrod 1972, 1974, Tirel 1982). Within Australia, it is restricted to the eastern coast and parts of the Northern Territory. *Elaeocarpus* in Australia is essentially a rainforest genus restricted to mesic forest communities. Some of the extant *Elaeocarpus* taxa in

northeastern Queensland are considered closely related to these fossil taxa from southeastern Australia. This would suggest that the montane areas near Cairns and Mackay in north Queensland region are refugia for species with affinities to these fossil taxa. The tropical rainforest communities in North Queensland, with their edaphic and physiographic diversity, are the last refuges in Australia for some of these Tertiary groups. The reduction in range and/or migration of taxa to refugial rainforest communities can be correlated with the increasing aridity of the climate from the Miocene onwards (Sluiter & Kershaw 1982). This deterioration in climate is thought to be due to the initiation of the circum-Antarctic current following the final severing of contact between Australia and Antarctica (Kemp 1978, Truswell & Harris 1982).

The fossil fruit record provides evidence that the genus was present on the Australian mainland prior to contact with the southeast Asian island arc. The fossil record of *Elaeocarpus* in Australia, as exemplified by the diversity of fruit morphotypes in the mid-Tertiary in Australia, indicates that the genus was morphologically diverse at this time (Kirchheimer 1935, Selling 1950, Blackburn & Sluiter, 1994, Rozefelds 1990a, b, Rozefelds & Christophel, this paper, 1996). The fossil taxa *E. clarkei* and *E. peterii*, in particular, have close affinities to modern species, e.g. *E. bancroftii* and *E. linsmithii*, and *E. stellaris* respectively, that are restricted to rainforest areas in northeastern Queensland (fig. 2).

The mid-Tertiary fossil fruit record (Selling 1950, Rozefelds 1990a, b, Blackburn & Sluiter 1994) from Australia suggests that the Australian plate could have been an important "corridor" for the evolution and radiation of parts of the genus into southeast Asia. The fleshy fruits are eaten by birds, and bird-mediated dispersal into southeast Asia from Australia (Firth 1982) could have occurred towards the end of the Miocene, following contact with the Indo-Malaysian island arc (Johnson & Briggs 1975). Clearly bird-mediated dispersal is the explanation for the genus in Hawaii. Similarly, the presence of *Elaeocarpus* on the late Tertiary volcanic island arcs in the New Hebrides and Solomon Islands would again suggest dispersal of fruits by birds as the most likely mechanism. Fruit-eating pigeons, as one example, regularly utilise *Elaeocarpus* fruits in their diet (table 2).

The alternative and probably ancillary explanation for the presence of *Elaeocarpus* in the southeast Asian region is rafting of micro-continental fragments from the northern rim of the Australian plate westwards. These fragments may have carried Gondwanic elements of the flora into the Indo-Malaysian region (Michaux 1991, Burrett *et al.* 1991), and parts of the Indonesian island arc are also likely to be Gondwanic in origin. A detailed phylogenetic analysis of taxa in the southeastern Asian and Australian regions may help to elucidate which of these biogeographical scenarios is most likely.

ACKNOWLEDGEMENTS

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TABLE 2
Distribution and species of pigeons utilising *Elaeocarpus* fruits in their diet*.

Pigeon	*Elaeocarpus* species	Distribution of pigeon
Wompoo pigeon *Ptilinopus magnificus*	*E. grandis, E. grahamii,* *E. largiflorens*	Northeastern Australia, New Guinea
Purple-crowned pigeon *Ptilinopus superbus*	*E. grandis, E. largiflorens* *E. arnhemicus, E. grahamii*	Northeastern Australia, New Guinea, Moluccas, Sulawesi, Sulu Island, Aru Islands, Bismarck Archipelago, Admiralty Islands, Solomons
Torres Strait pigeon *Ducula spilorrhoa*	*E. grandis*	Northeastern Australia, Northern Territory, New Guinea, Aru Islands, Bismarck Archipelago, Admiralty Islands
Top knot pigeon *Lopholaimus antarcticus*	*E. kirtonii, E. grandis*	Eastern Australia

* from Firth (1982)

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PATTERNED QUAKING MIRE AT HANDSPIKE POINT, MACQUARIE ISLAND

by J. Rich

(with two tables, eight text-figures, two plates)

RICH, J., 1996 (30:vi): Patterned quaking mire at Handspike Point, Macquarie Island. *Pap. Proc. R. Soc. Tasm.* 130(1): 49–65. ISSN 0080–4703. School of Biological and Environmental Sciences, Murdoch University, Murdoch, Western Australia 6150.

Raised mires occur on an emerging marine terrace of Holocene age at Handspike Point, Macquarie Island, and slope seawards. Portions of these mires are characterised by numerous, anastomosing to parallel, low peat ridges, separated by waterlogged troughs. The resulting patterns are accentuated by the distinctive rosette plant *Pleurophyllum hookeri* , which grows only on the ridges. Sampling suggests that ridge and trough patterns persist to at least 1.5m depth. *Pleurophyllum* colonisation appears to be a function of the difference in trough:ridge peat bulk density. As this density ratio approaches 0.8, waterlogging decreases and *Pleurophyllum* vigour is enhanced.

Patterns are oriented at various angles to the present surface slopes, but roughly parallel to the plateau margin and normal to the regional slope of the marine terrace. The divergence between pattern and local contour orientation results from non-uniform accretion. Patterns at angles to the contours appear to provide benefits which include enhanced water-level stability.

The Handspike mires exhibit many characteristics of patterned and non-patterned peatlands ubiquitous throughout the Northern Hemisphere, with particular similarities to eccentric domed mires of the Baltic region. Vertical accretion is estimated to average 1mm yr^{-1}; lateral accretion appears to be in equilibrium with the emerging marine terrace.

Key Words: Patterned mire, raised mire, peat, Macquarie Island, subantarctic.

INTRODUCTION

Macquarie Island (54°37'S, 158°53'E) is seismically active and is rising at rates variously estimated to be between 1.7 and 4.5 mm yr^{-1} (Colhoun & Goede 1973, Adamson *et al.* 1988). Prior to sea-level stabilisation 6000 to 7000 years ago, sea level rose faster than the island, resulting in vigorous marine erosion and coastal cliff retreat (Adamson *et al.* 1988). Continuous uplift since that time is reflected in a raised marine terrace which is now the dominant landform along the northern two-thirds of the west coast (Blake *in* Mawson 1943, Colhoun & Goede 1973, Selkirk *et al.* 1990b). This terrace is up to 1 km wide and rises from the shore at slopes of 2° to 4° (Adamson *et al.* 1988). Steep slopes or cliffs form the inland edge of the terrace and define the limit of former marine erosion. The climate is dominated by persistent, strong west to northwesterly winds, frequent low cloud and fog, and a narrow range of temperature.

Water-saturated quaking mires, known locally as featherbed, occur in a number of areas along the raised marine terrace. At Handspike Point, quaking blanket mire is the dominant landform (fig. 1). Portions of the Handspike mires display distinctive linear patterns which have not been described from elsewhere on Macquarie Island. These consist of slightly elevated, relatively drier peat ridges, separated by wetter troughs. The resulting striped pattern is further accentuated by the distinctive, large-leafed, grey-green rosette plant *Pleurophyllum hookeri* Buchan, which grows on many of the ridges. The patterns were first described by Hamilton (1926), biologist with Mawson's 1911–1914 Australasian Antarctic Expedition (AAE) party. Hamilton considered that the stripes were parallel to the prevailing wind direction and that *Pleurophyllum* seeds were distributed down wind, seedlings establishing in the lee shelter provided by the parent plants. This theory was reiterated by Taylor (1955), who also considered the lines to be roughly parallel to the prevailing winds. Selkirk *et al.* (1990a) were the first to point out that the stripes are not parallel to the prevailing wind. They noted that their origin remained unexplained.

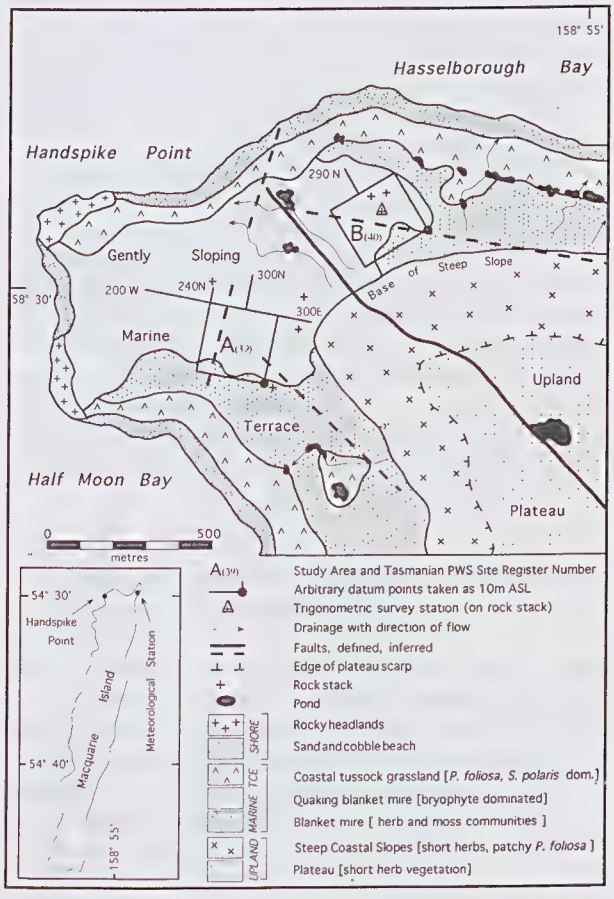

FIG. 1 — Location map showing physiography, vegetation communities and study areas.

Patterned peatlands are widespread throughout the temperate and subpolar regions of the Northern Hemisphere. They include such land forms as string bogs and fens (Sjors 1961, Washburn 1979, Glaser & Janssens 1986) and various forms of patterned mires (Moore & Bellamy 1974, Glaser *et al.* 1981). Patterned peatlands include domed or raised mires and bogs in which convex masses of peat grow above the original water table (Moore & Bellamy 1974). In all of these features, peat strings or ridges of relatively higher relief are separated by depressions (troughs or flarks) which are commonly water-filled. Numerous hypotheses have been advanced to explain specific examples (Thompson 1983, Foster *et al.* 1983, Kirkpatrick & Gibson 1984, Whinam 1985). However, it is likely that superficially similar landforms develop on different sites through a number of processes, each with varying biotic, periglacial and gravitational components (Moore & Bellamy 1974). Wetlands may be either zones of ground water recharge or discharge (Siegel 1988). The distribution of ombrotrophic bogs and minerotrophic fens may be largely controlled by local ground water flow systems (Siegel 1983). Climate, particularly precipitation and presence or absence of an annual period of freezing, also appears important, and the classification and distribution of many forms of patterned peatland have been tied to climatic factors (Drury 1956, Thom 1972, Brown & Péwé 1973, Moore & Bellamy 1974, Dewez *et al.* 1984).

During the winter of 1990, two study sites which included areas of *Pleurophyllum* stripes were established on the Handspike mires (fig. 1). These are included on the Tasmanian Parks and Wildlife Service (PWS) Macquarie Island Study Site Register as sites 39 and 40. It became evident from an early stage that Hamilton's "wind rows" and Taylor's "wind line complexes" were inappropriate names because they carried firm but as yet unjustified genetic connotations. The term "patterned mire" has been adopted to describe these features.

Despite speculation about the Handspike mires since at least 1911, no systematic physical surveys or descriptions had been made prior to this study. Probing showed that the mires are very deep (up to 5.9 m) and suggested that the surface patterns persisted at depth. The present paper presents the first detailed description of the surface and subsurface characteristics of the Macquarie Island patterned mires and provides evidence that the present surface patterns were formed at an early stage of mire development and have persisted during vertical accretion. In places, the patterns may provide an additional mechanism of water-level regulation within the mire.

PHYSIOGRAPHIC SETTING OF THE STUDY AREA

The principal physiographic features and vegetation communities are summarised in figure 1. Coastal tussock grasslands dominated by *Poa foliosa* (Hook. f.) Hook. f. and *Stilbocarpa polaris* (Homb. et Jacq.) Gray (Macquarie Island cabbage) fringe the beaches along Hasselborough Bay and Half Moon Bay. A rise in elevation of several metres in many places defines the landward transition to blanket mires. The mires have convex surfaces which vary from smooth to hummocky and consist of peat, supporting mixed and highly variable herb and moss communities. Taylor (1955) and Selkirk *et al.* (1990a) provided detailed descriptions. Within the blanket mire are extensive areas of bryophyte-dominated quaking mire, portions of which are patterned. Transition from blanket to quaking mire varies from gradational to sharp. At Handspike Point, the quaking mires extend west to the beach, where they are punctuated by numerous rock stacks and low outcrops. A transition zone approximately 100 m wide, parallel to the beach, is characterised by numerous staircase ponds dammed by the cushion plant *Azorella macquariensis* Orchard.

Steep (25°–35°) coastal slopes rise from the inland edge of the raised marine terrace to the island plateau. The slopes support short-herb communities mixed with patchy *Poa foliosa* and *Stilbocarpa polaris*. Short-herbfield vegetation predominates on the plateau.

Study Areas A and B collectively comprise 8.4 ha and include the largest areas of patterned mire. The Handspike Point patterned mires (estimated total extent 12 ha) represent the only reported occurrence of this landform on the island.

MATERIALS AND METHODS

Survey grids defined by wooden pegs (lines 20 m apart, pegged every 10 m) were placed over Area A (200 × 200 m) and Area B (200 × 220 m). All grid points in both areas were optically levelled, to an accuracy of ± 1 cm, each with an arbitrary datum (fig. 1). No attempt was made to tie the two surveyed areas together, nor were the datum points tied to sea level, or the trig. station. Detailed maps of surface topography were prepared for each area. Mire thickness was measured by probing along selected grid lines at 10 and 20 m intervals using a 6 m length of 13 mm copper pipe. These data were tied to the surface levels, and detailed sections of the subsurface topography were constructed. Surface and subsurface slopes were calculated by linear regression. Rate and direction of surface water flow were determined using water-soluble food dyes.

Continuous vertical cores of undisturbed mire were collected varying from 300 mm to 1500 mm depth, using a sampler adapted from 130 mm diameter stainless steel flue pipe (pl. 1A). These cores, of both ridge and trough material, were cut into segments each 300 mm in length and dried to constant weight, each segment representing 3982 cm^3 of wet mire material. The abundance of *Pleurophyllum hookeri* on the ridges adjacent to the sample sites was mapped, using a relative scale of absent, rare, common and abundant.

The mires are extremely fragile and difficult to walk on. In many parts, they will not support a person's weight. Footprints persist as holes in the mire surface for years. Snowshoes were used to provide adequate support for walking over the mire surface, their faint impressions disappearing over a period of a few months.

SURFACE TOPOGRAPHY AND MORPHOLOGY OF THE MIRES

Surface topography and mire patterns are superimposed in figures 2 and 3. Various relationships occur locally in both areas between pattern orientation and present surface topography. However, when viewed regionally it is apparent that pattern orientation is more or less normal to the mean terrace slope and parallel to the edge of the plateau. Within

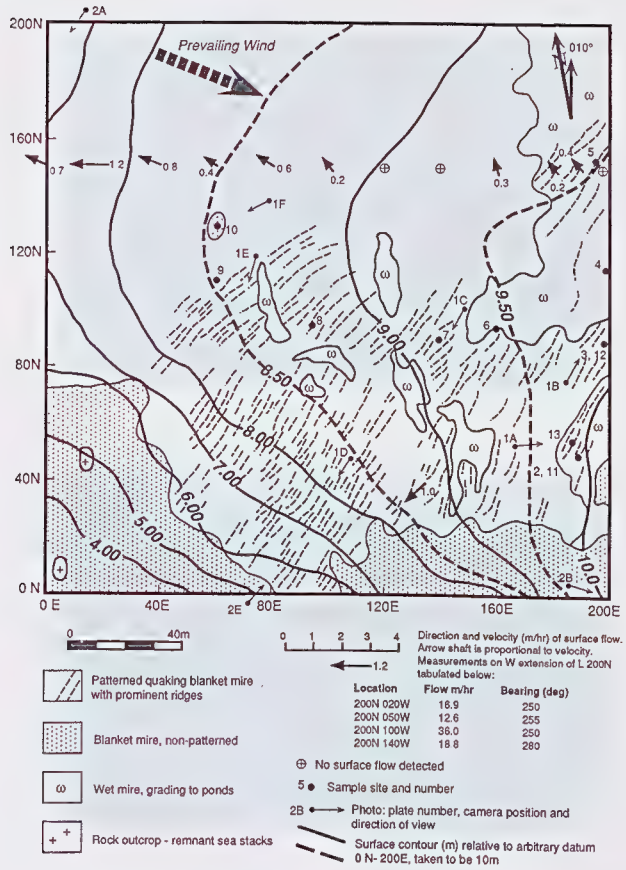

FIG. 2 — Area A: surface contours, sample locations, surface water flow data and details of mire patterns. Only the more prominent ridges are shown, drawn from air photo enlargements. Ridge patterns in the north and east of the survey area could not be reproduced accurately from the available air photographs. Note the orientation of the prevailing wind relative to the mire patterns and the variable relationship between the contours and pattern orientation. The contours were constructed from 231 surveyed points.

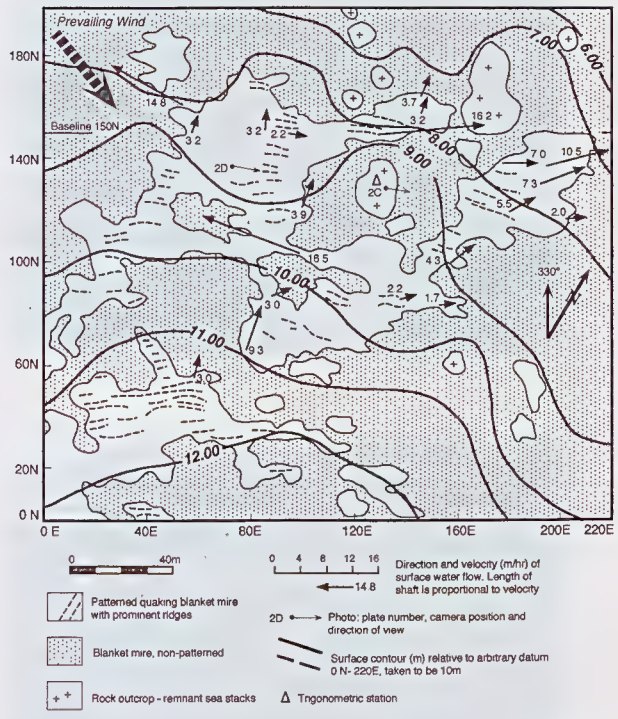

FIG. 3 — Area B: surface contours, surface water flow data, and details of mire patterns, drawn from air photo enlargements. Transition from patterned to non-patterned ground is generally sharp. Length of water flow arrows is proportional to flow rate (note: scale is 4× that in fig. 2). Local flow direction is controlled by both the ridges and the regional slope. Compared to Area A, surface slopes are steeper. As a consequence, flow rates are greater, ridges exhibit a greater tendency to be convex down slope, and there is a closer correlation between contours and pattern orientation. Contours were constructed from 245 surveyed points.

Area A, pattern orientations vary from 045° to 055°. Area B is located where the plateau edge changes orientation from NNE to ENE, becoming parallel to Hasselborough Bay. There is a corresponding change in pattern orientation from 060° to 085°, the more easterly orientations corresponding to the more easterly alignment of the plateau.

Area A

The mire patterns comprise a series of roughly parallel ridges and troughs. Total relief between ridge and adjacent trough varies from 0.1 to 0.2 m, the ridges being markedly drier than the intervening troughs. The water table fluctuates but normally lies at or slightly above the surface level of the troughs, which commonly contain several centimetres of water. During heavy or prolonged rain, the troughs act as gutters, channelling water off the raised mire. Trough areas which had been water filled throughout the winter of 1990 were dry after a five-day period of little rain in November.

Patches of non-patterned quaking mire also exist. They consist of irregularly shaped wet areas containing structureless mats of bryophyte vegetation, which may grade into and surround small open ponds. The wet areas are near-horizontal with contour-parallel long axes. The mats quake and provide little support, even with snowshoes. A series of such features lie parallel to the 8.5, 9.0 and 10.0 m contours (fig. 2, pl. 1B, C) and are interpreted to represent former areas of open water.

Wide variation in mire pattern occurs both within and between the two study areas. Patterns can be characterised on the basis of ridge length and spacing, and trough morphology. The ridges and troughs commonly display anastomosis. Troughs are defined as open where they form an interlacing network of branching and reuniting channels. There is a gradation to a pattern where it is the ridges which branch and reunite, leaving the troughs as closed linear depressions. The greatest variation occurs in Area A, as illustrated in plates 1 and 2 and diagrammatically in figure 4, where five basic patterns have been identified.

(a) *Long ridges:* occur adjacent to wet, non-patterned mire, characterised by long, widely-spaced parallel ridges and open troughs. Ridges in many places display continuity over 20 m and are separated by waterlogged troughs, which provide little support and are difficult to traverse.

(b) *Open, broadly patterned mire:* lateral gradation from (a) occurs typically within a distance of 10 m. Individual ridges and troughs become shorter, typically 8–14 m, and the

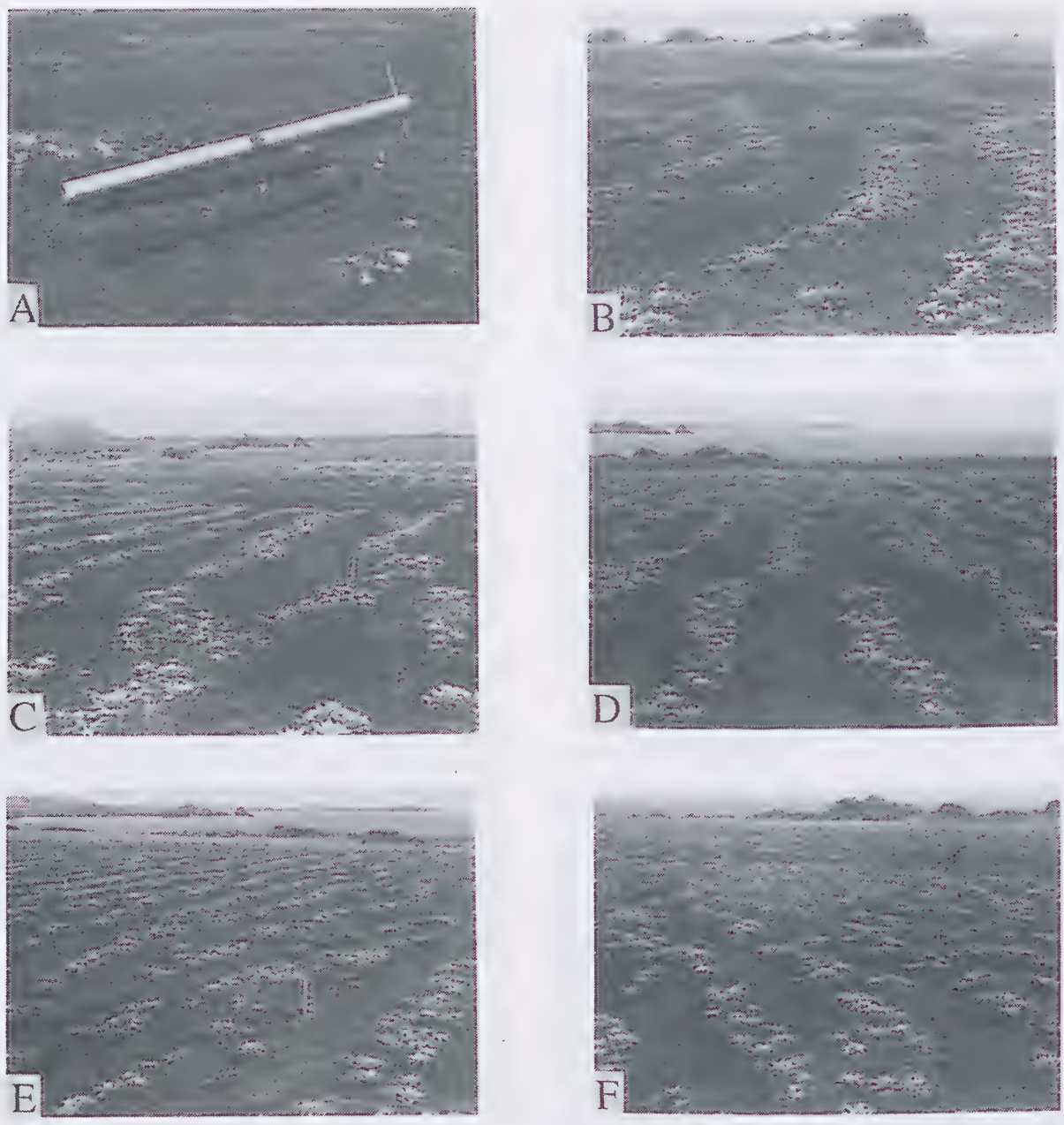

PLATE 1

(A) Sampler used to collect volumetrically undisturbed samples, Area A. Cores of ridge and trough material, sample 13a (beside sampler) and sample 13b (foreground), ready for division into 300 mm sample lengths.

(B) Area A, long, widely spaced ridges at 90N 200E bordering non-patterned wet mire (top and left of photo). Pleurophyllum *is rare to common on the ridge to the left and common to abundant on those in the foreground.*

(C) Area A, long ridges of well-developed patterned mire. Peg in middle foreground is 90N 140E. Non-patterned mire in middle distance is the wet area centred at 70N 130E which lies parallel to the 9.0 m contour (fig. 2).

(D) Area A, well-developed patterned mire, with open troughs aligned down slope and ridges accentuated by Pleurophyllum hookeri. *Troughs, which normally contain several centimetres of water were dry when photos were taken in November 1990.*

(E) Area A, open, tightly patterned mire. Peg in foreground is 100N 60E. Note that, despite the tighter row spacing, there is still downslope continuity within the troughs.

(F) Area A, tightly patterned mire in foreground, island of non-patterned mire in distance with vestigial Pleurophyllum hookeri *patterns. Note that troughs have become closed, resulting in impoundment of water during heavy rain.*

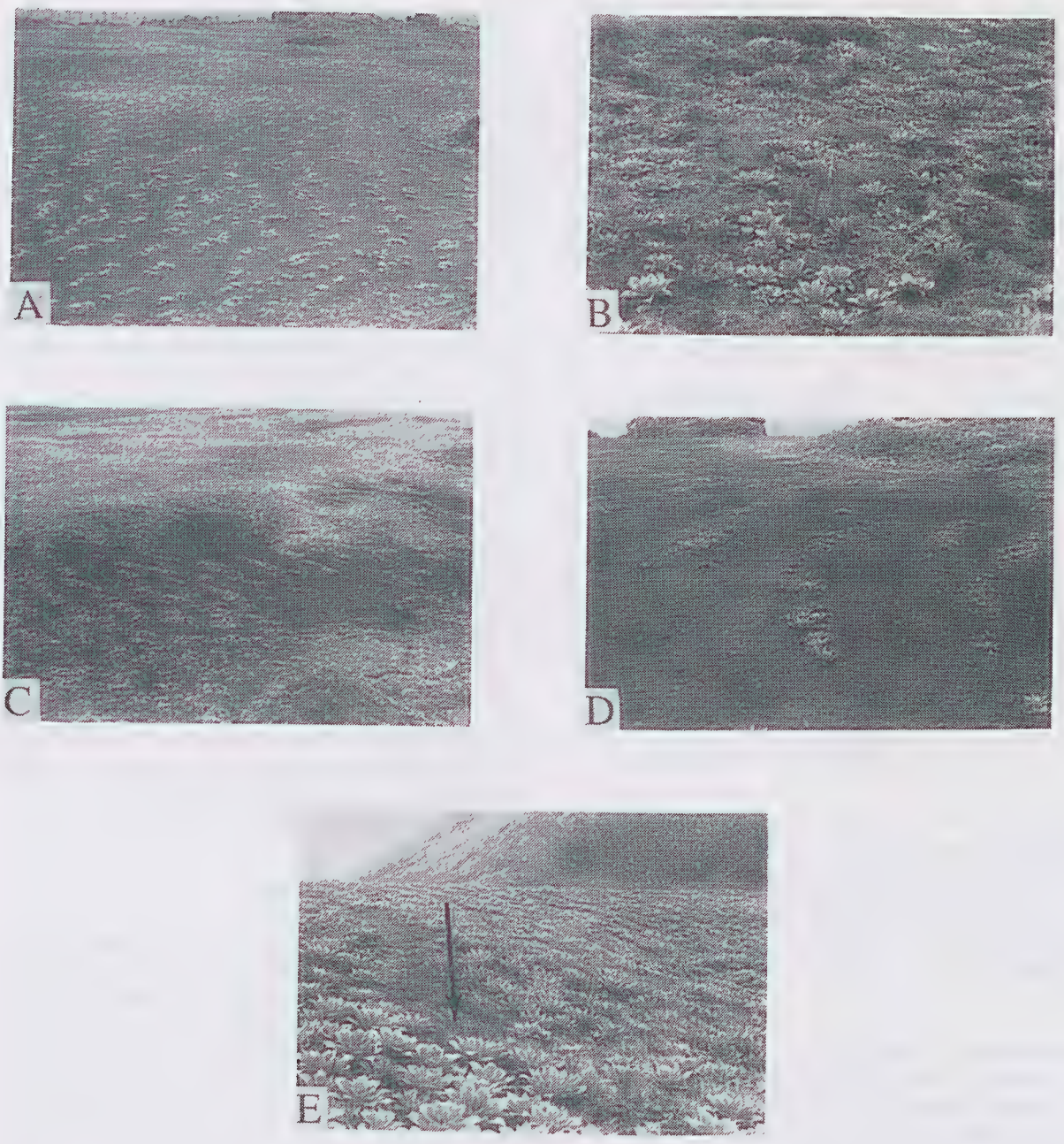

PLATE 2

(A) Diffusely patterned mire with closed troughs, sparsely colonised by Pleurophyllum hookeri. *Note the narrow ridges which in most places support only single rows of* Pleurophyllum.

(B) Non-patterned blanket mire, SE corner, Area A. Compared with the patterned mire, the ground is firm with a predominance of angiosperms. Pleurophyllum hookeri *is more robust than on the adjacent mires.*

(C) Typical patterned mire, Area B. Patterned mire occurs within small, scattered zones of very wet quaking mire surrounded by non-patterned blanket mire.

(D) Curved ridges, convex down slope, Area B. Note sea stacks in background.

(E) Ridge and trough patterns preserved along the steeply sloping southern margin of Area A, where patterned mire grades into non-patterned blanket mire and coastal tussock grassland. Ridges support abundant Pleurophyllum hookeri *(foreground). Troughs are open, normal to slope (indicated by arrow) and channel water off the raised mire during heavy rain. Slope is 8°.*

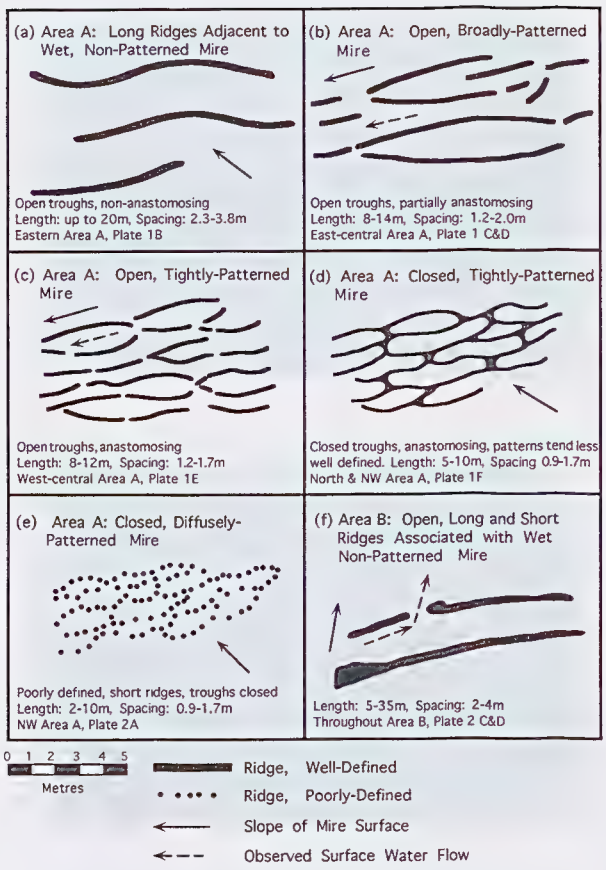
(a) Area A: Long Ridges Adjacent to Wet, Non-Patterned Mire
Open troughs, non-anastomosing
Length: up to 20m, Spacing: 2.3-3.8m
Eastern Area A, Plate 1B
(b) Area A: Open, Broadly-Patterned Mire
Open troughs, partially anastomosing
Length: 8-14m, Spacing: 1.2-2.0m
East-central Area A, Plate 1 C&D
(c) Area A: Open, Tightly-Patterned Mire
Open troughs, anastomosing
Length: 8-12m, Spacing: 1.2-1.7m
West-central Area A, Plate 1E
(d) Area A: Closed, Tightly-Patterned Mire
Closed troughs, anastomosing, patterns tend less well defined. Length: 5-10m, Spacing 0.9-1.7m
North & NW Area A, Plate 1F
(e) Area A: Closed, Diffusely-Patterned Mire
Poorly defined, short ridges, troughs closed
Length: 2-10m, Spacing: 0.9-1.7m
NW Area A, Plate 2A
(f) Area B: Open, Long and Short Ridges Associated with Wet Non-Patterned Mire
Length: 5-35m, Spacing: 2-4m
Throughout Area B, Plate 2 C&D
0 1 2 3 4 5
Metres
Ridge, Well-Defined
Ridge, Poorly-Defined
Slope of Mire Surface
Observed Surface Water Flow

FIG. 4 — Schematic mire patterns. Area A displays a much greater diversity of patterns compared to Area B. Irregular lines 4(e) denote very narrow and ill defined ridges defined by clumpy development of Pleurophyllum. *Ridges in Area B are often markedly convex down slope. Water is channelled laterally behind the ridges and descends through gaps to the next ridge level.*

spacing between them tighter, typically about 2.0 m. The most distinctive difference is the partial development of anastomosis. These are the typical "wind row" areas described by earlier workers.

(c) *Open, tightly patterned mire:* ridge spacings as close as 1.2 m, strongly anastomosing. Where ridge spacing is greatest, troughs tend to be deeper. Surface water flows freely between the troughs during rainy periods and forms disjointed pools during drier weather.

(d) *Closed, tightly patterned mire:* predominant in the northwestern portion of Area A. Ridges, rather than the troughs, branch and unite, leaving the troughs isolated from each other. During periods of heavy rain, water is impounded within the troughs.

(e) *Closed, diffusely patterned mire:* characterised by a somewhat chaotic pattern of poorly defined but roughly linear, narrow ridges supporting sparse, clumpy *Pleurophyllum.* Troughs are reduced to numerous, closed, ovoid depressions.

Whereas the very long ridges bordering the wet areas are indeed "quaking" in nature, both the ridges and troughs are noticeably firmer in the tightly patterned areas.

There are several islands of well-vegetated, non-patterned mire. The largest, located at 130N/60E, measures about 5 × 10 m (fig. 2, pl. 1F). It includes what appear to be vestigial ridges, defined by diffuse linear patterns in the *Pleurophyllum.*

Transition from raised, quaking, patterned mire to non-patterned blanket mire takes two forms. Around the southwestern and southern portions of the study area, the raised mire stands 2– 4 m above the surrounding blanket mire. Here, the transition is marked by a steepening of the convex slope to about 8° and a distinct change in vegetation at the foot of the slope. Frequently the ridge–trough patterns are preserved on this slope (pl. 2E) but terminate sharply at its base, which is also marked by a general increase in firmness (or decrease in wetness) of the peat, increased abundance of both *Pleurophyllum hookeri* and *Stilbocarpa polaris*, and decreased abundance of bryophytes. Along the eastern portions of the raised mire, there is frequently a sharp transition from non-patterned wet mire to firm mire, with abundant *Pleurophyllum* and *Stilbocarpa* (pl. 2B) where the slope of the blanket mire increases towards the base of the steep plateau slopes (fig. 1).

The orientation of the ridge–trough patterns is roughly constant but varies from contour-parallel in the northeastern third of the survey area to contour-normal in the south. In general, however, most of the ridges and troughs are oriented across the contours, so that the troughs act as drains for the flow of surface water from the mire surface. Overall, Area A exhibits extremely low relief. Mean surface slopes across the surveyed grid on line 200N are only 0.7°–0.5° W over the 200 m portion of the line lying within Area A (fig. 5A). The raised nature of the mire is evident in section (fig. 5A, C, D). The central portion is a gentle, convex, elongate dome trending E–W, with vertical relief of about 1 m. This feature is defined by the 8.5– 9.5 m contours (fig. 2).

Area B

Area B (fig. 3) contains scattered, partially-disjointed areas of very wet quaking mire with large-scale ridges, surrounded by non-patterned mire (pl. 2C). The transition between these mire types is sharp, typically occurring over 1–2 m horizontally. Compared with Area A, there is little variation in pattern morphology. Ridges tend to be parallel, less well-defined and vary greatly in length, with a variable spacing which averages about 3 m (fig. 4F). In plan, they are commonly convex down slope (fig. 3, pl. 2D). Individual ridges frequently display a stepped pattern, the top of each being slightly lower than that of the adjacent upslope ridge, resulting in a series of very low terraces. Water is pooled behind each ridge at levels which may differ by a few centimetres, resulting in a series of staircase ponds of very subdued vertical relief. Water may also flow laterally along a ridge until it reaches a gap where it can descend to the adjacent down slope trough (fig. 4F).

There is close correlation between mire surface slope and ridge–trough orientation. In the western half of Area B, the ridge–trough patterns and the contours both trend about 060°, and in the northeastern portion of the area both the contours and the mire patterns trend about 085°. Slopes here are double to triple those in Area A (fig. 6). As a result, small variations in surface elevation during mire accretion have had a much less pronounced effect on the overall contour pattern. This is in direct contrast to Area A where subtle variations in rates of mire accretion have resulted in large differences between pattern and contour orientation.

Non-patterned raised mire around the northern and

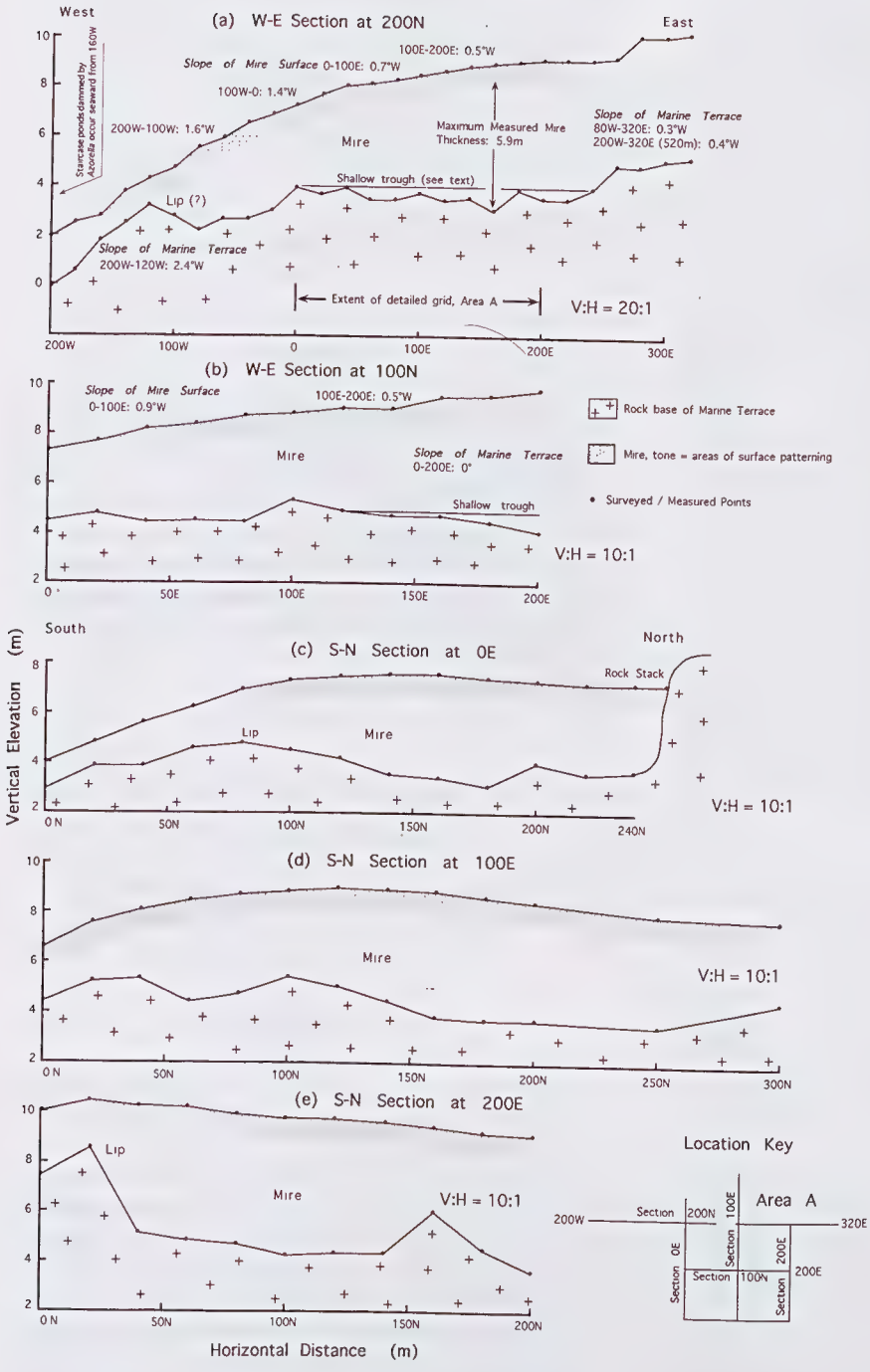

FIG. 5 — Area A: W–E and S–N Sections. Around the west and south margins, the raised, patterned mire thins and drops away to non-patterned blanket mire. Note the low bedrock lip along these margins, and steep subsurface walls of the rock stack. Section 200N includes the grid extensions shown in figure 1 (note the changes in horizontal scale and vertical exaggeration). The marine terrace in Sections 100N and 200N displays local easterly (landward) dips. Overall terrace dip however is very gently westward. Section 200N shows how both the mire surface and the terrace steepen seaward. The vertical scale exaggerates local irregularities and the convex surface of the raised mire. Elevations and distances are relative to the arbitrary datum shown in figure 1.

eastern margins grades rapidly to hummocky blanket mire. The margin of the raised mire forms a 1–3 m high steep bank and also defines an abrupt change in water table altitude. There is, however, little surface seepage across this boundary.

SUBSURFACE TOPOGRAPHY OF THE MARINE TERRACE

The marine terrace, where exposed in penguin rookeries elsewhere on the island consists of a very gently undulating, water-rounded beach cobble pavement over a sand and gravel substrate, rising gently to the base of the inland cliffs. Probing through the Handspike mires shows a sharp contact between overlying peat and the terrace surface, which is presumed to be similar to that observed in the rookeries.

Area A

The average slope of the marine terrace is down to the west, with numerous small irregularities (accentuated by the difference in vertical and horizontal scales used in the figures). These are best observed on L 200N (fig. 5A) where data was collected over a lateral distance of 520 m. On L 200N, maximum altitude variation is only 5.4 m over 520 m, with an average slope of 0.4° W. Irregularities such as the lip at 120W have a relief of only about 1 m. The central section of the terrace is a very shallow trough (fig. 5A). The

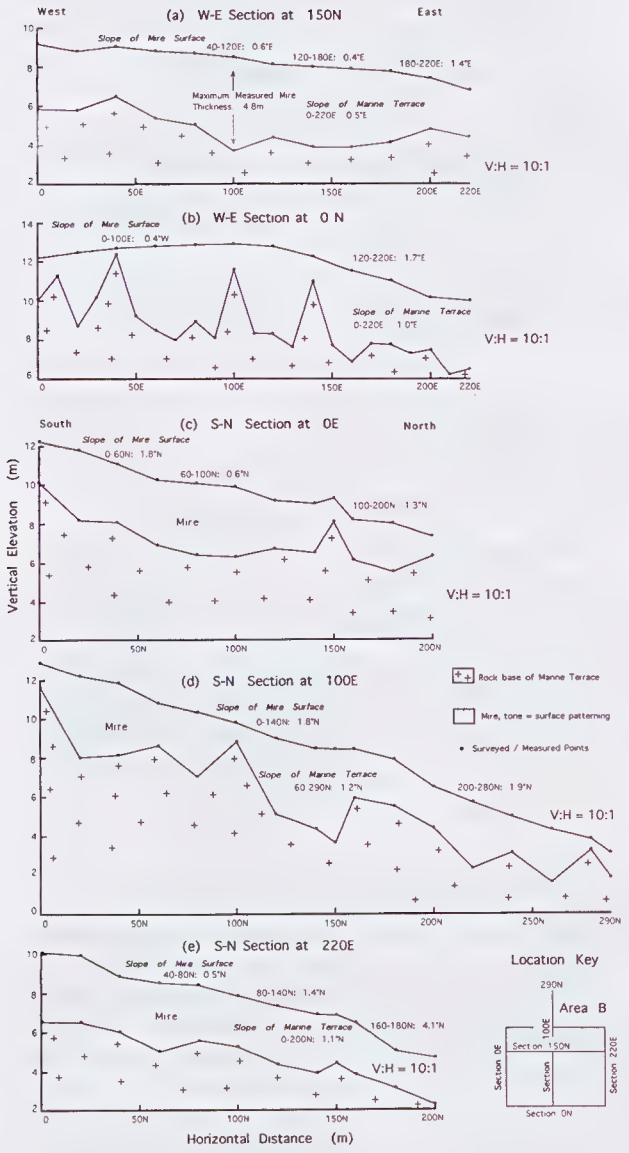

FIG. 6 — Area B: W–E and S–N Sections. The thickest patterned mire occurs over depressions in the marine terrace. Small sea stacks enveloped by mire are evident in Section 0N. Surface and subsurface slopes tend to be steeper than those in Area A, and the marine terrace is much more irregular. Note how the topography of the marine terrace is frequently mimicked in the mire surface. This is most evident in the S–N sections. Elevations and distances are relative to the arbitrary datum shown in figure 1.

irregularities reflect minor differential erosion of bedrock by the sea, when the terrace was flooded earlier in the Holocene. While the mire surface of the detailed gridded area from 0E to 200E has westerly dips of 0.5°–0.7°, the underlying terrace has an overall easterly dip of 0.1°. This pattern persists on L 100N, with westerly surface dips of 0.9°–0.5° but an average terrace slope of 0° (fig. 5B). In summary, the surface of the mire dips more steeply than the underlying marine terrace.

The mire reaches its maximum measured thickness of 5.9 m at 200N/160E, and an average thickness of approximately 5 m is maintained to within 20 m of the plateau scarp base. On the seaward side there is a suggestion of a lip or ridge at 120W. On section 100N the mire reaches a maximum thickness of 5.5 m at 200E. North–south profiles on lines 0E, 100E and 200E (fig. 5C–E) give the clear impression that the terrace floor below the southern edge of the mire is also slightly raised or lipped and may have acted, during the early stages of mire formation, as a natural retaining structure. This, combined with the trough noted above, suggests that, in the early phases of terrace emergence, subtle natural topographic depressions may have resulted in ponding close to the base of the plateau slope. The present-day open ponds and very wet non-patterned mire discussed above, occur now over this feature. Ponding is frequently augmented by vegetation. Fossil topography can act as a template for initial establishment of bolster species which raise themselves into dams resulting in significant modification of surface flow (Kirkpatrick & Gibson 1984, Whinam & Kirkpatrick 1994). A similar process may be occurring today seaward of Area A, where numerous small staircase ponds are controlled by bolsters of *Azorella macquariensis*.

Rock stacks (former sea stacks) occur around the periphery of the survey area. Probing adjacent to the stacks shows that their steep sides descend more or less vertically to the terrace floor. Adjacent mires are commonly 3–4 m thick.

Area B

The patterned mires are on average 3–4 m thick (i.e. 1–2 m thinner than those in Area A) and exhibit a much more irregular distribution. Subsurface topography is also much more variable. The marine terrace slopes seaward at angles in excess of 1°, i.e. double or triple the average 0.4° of

Area A (figs 5A, 6). Here also, the distribution of patterned mire suggests a relationship with depressions on the marine terrace. Maximum mire thickness (4.8 m) occurs at 150N/100E, corresponding to the centre of the largest patch of patterned mire (fig. 6A). Similar relationships are suggested on sections 0E and 100E (fig. 6C, D). The most striking features are the numerous rock stacks which protrude through the mire (pl. 2D). These are steep to vertical sided, both above and below the mire surface. Adjacent mires, such as at 150N/160E may be up to 4 m thick. Many of the subsurface irregularities evident in the profiles are probably rock stacks enveloped by the growing mire.

The mire surface frequently reflects the underlying terrace topography. High points (typically with a relief of 1–2 m) on the terrace are mimicked by subtle (<0.5 m) features at surface. During the initial stages of terrace emergence, mire forms as thin, disjointed patches within local depressions. At the same time vegetation, particularly bryophytes, colonises the tops of rock stacks and large cobbles. Where observed today, such caps are frequently draped over the supporting structure. They are generally <0.5 m thick and are presumably moisture-limited. As rock stacks are enveloped by the developing mire, their capping vegetation (particularly draped vegetation) is prematurely incorporated into the mire. The cap then commences vertical accretion (possibly in response to increased moisture) at approximately the same rate as the surrounding mire and is preserved as a subtle topographic high.

Depth probing data (fig. 6) indicate that the surface highs remain aligned over the original terrace features (e.g. section 0E, 150N, section 100E, 160–200N and section 220E, 150N). This suggests that vertical accretion predominates over any downslope mass flow. Enveloped rock stacks which are not mimicked on the mire surface probably had little or no capping vegetation.

HYDROLOGY

Mire hydrology is doubtless a complex relationship between terrace and surface slopes, minor surface irregularities such as the ridges and troughs, the internal morphology and hydraulic conductivity of the mire peats, rainfall, evaporation and transpiration. The mires appear to be predominantly ombrotrophic and act as giant sponges, holding vast quantities of water through capillary action and adsorption to colloids (Ivanov 1981).

Surface flow tests in Area A were carried out on L 150N in May 1990 when the troughs were water-filled. Here the slopes are low and the ridge–trough patterns are approximately contour-parallel (fig. 4D, E typifies this situation). Dye (10 ml), placed in the centre of a trough, flowed laterally, becoming impounded against the ridge on the downslope side. Eventually traces of dye would appear in the adjacent downslope trough, having flowed through the peats of the intervening ridge. Flows were found to be roughly normal to the surveyed contours, but the relatively low surface slopes and the necessity for the water to flow through the ridges impeded the flow and resulted in average flow rates which varied from negligible to 1.2 m hr^{-1} (fig. 2). Further west, where the mire slopes more steeply towards the coastal ponds, water flows visibly along the troughs. Dye tests on L 200N, west of the survey area, indicated surface flow rates of up to 36 m hr^{-1}. Local surface slopes here are up to 3.7° west. A single test was carried out at 40N/135E (fig. 2), where the contours are oriented 70° to the ridge–trough patterns. Run-off from early morning rain was flowing visibly in the more steeply sloping troughs around the southern periphery of the mire (pl. 2E). However, at the test site there was no visible flow. Standing water in the trough was 10–20 mm deep. Over 50 minutes, dye placed in the centre of the trough traced a curving flow path, finally becoming impounded against the west side of the trough, 800 mm down slope of the start point, at a flow rate of 1.0 m hr^{-1}. This confirmed that flow direction is controlled both by the subtle surface slopes and the troughs, which effectively act as gutters forcing flow at various angles to the contours. Much more extreme examples of this occur in Area B where the increased gradient is evident in the flow rates (measured in June 1990), which varied from 1.6 to 16 m hr^{-1}, both parallel to and across the ridge–trough patterns (figs 3, 4F).

Peat comprising the ridges exhibits a considerable resistance to the lateral subsurface flow of water. In a simple test, three 0.5 m deep, vertical-walled pits were dug in ridged mire at sample sites 11, 12 and 13. The adjacent troughs, lying approximately a metre either side, were water logged and contained standing water. The pits took 5 to 10 minutes to fill. Water trickled slowly down the pit walls and also appeared to be moving vertically up through the pit floor. The hydraulic conductivity of the ridge peats is clearly lower than that of the trough peats. The ridges impede the surface and near surface flow of water off the mire. Therefore, during heavy rains troughs act as gutters, channelling water to the edge of the mire.

SURFACE PEAT SAMPLING

Peat is taken to include living surface vegetation plus dead and decaying plant tissues comprising the mires. It is evident to anyone walking on the mires that the ridges are much denser than the troughs. The ridges support a person while the troughs often do not. Depth probing through adjacent ridge trough sets showed the same thing and provided the initial evidence that the surface patterns persisted at depth as density differences.

Undisturbed 300 mm long peat cores were collected from sites in Area A (fig. 2, table 1). Samples were collected from non-patterned mire, wet non-patterned mire and from a number of different sites in the patterned mires, where sample sets (designated a and b) were collected from adjacent ridges and troughs. Distance between ridge centres and average ridge length was measured, plus the relative abundance of *Pleurophyllum hookeri*. The bulk density of peat (dry weight per unit fresh volume, including voids, expressed as % w/v) provides a measure of peat density. It is also a relative measure of the degree of decomposition (Chason & Siegel 1986) and is inversely proportional to hydraulic conductivity (Boelter 1969). Handspike values range from 2.5% to 6.6% implying 93.4% to 97.5% water. These figures are in agreement with the 91% to 98% quoted by Ivanov (1981).

Peats from long ridges (fig. 4A, samples 2a, 3a, 11a, 12a, 13a), occurring adjacent to wet non-patterned mire, have bulk densities which are generally greater than those from ridges in the more tightly patterned mire (fig. 4B, C, samples 6a, 7a, 8a, 9a). Corresponding values for trough peats are less (sample 5a is an obvious exception). The data set is small but suggests that the large ridge–trough sets are

TABLE 1
Results of Surface Sampling, Area A

Sample*	Location		Ridge Peat		Trough Peat		T/R ‡	Width §	L ¶	Plr #	Comments
			Total†	% (w/v)	Total†	% (w/v)		(m)	(m)		
1	000N	200E	264	6.6						3	Non-patterned blanket mire
2a–2b	050N	190E	246	6.2	101	2.5	0.40	2.0–2.3	10	1	Large sinuous ridges adjacent
11a–11b	050N	190E	262	6.6	144	3.6	0.55	2.0–2.3	10	1	to non-patterned wet mire
3a–3b	090N	200E	235	5.9	99	2.5	0.42	1.8–2.3	10	2	Large sinuous ridges south
of											
12a–12b	090N	200E	205	5.2	159	4.0	0.77	1.8–2.3	10	2	non-patterned wet mire
4	115N	200E			127	3.2				0	Non-patterned wet mire
5a–5b	154N	195E	194	4.9	122	3.1	0.63	2.3–3.8	20	2	Long ridges between areas of non-patterned wet mire
6a–6b	095N	160E	216	5.4	194	4.8	0.88	1.6–2.1	8	1–3	Well developed ridges, *Pleurophyllum* rare to abundant
7a–7b	090N	140E	203	5.1	163	4.1	0.80	1.2–1.9	14	3	Very well developed even ridges
8a–8b	095N	095E	225	5.6	189	4.8	0.84	1.2–1.5	12	3	Indistinct ridges, partially fused, troughs weak to absent
9a–9b	110N	060E	204	5.1	172	4.3	0.84	0.9–1.7	9	3	Ridges short, anastomosing. *Pleurophyllum* abundant and vigorous
10	130N	060E	212	5.3						3	Island of non-patterned *mire, Pleurophyllum* in vestigial rows
13a–13b	055N	188E	218	5.5	103	2.6	0.47	2.0–2.3	10	2	Large sinuous ridges adjacent to non-patterned wet mire

* All samples are 0–300 mm in depth, a–b sample sets are ridge–trough pairs. Single sample numbers are from non-patterned mires. Samples 11a–11b, 12a–12b and 13a–13b represent the top portions of the deep profiles.

† Total (Ridge/Trough Peat) means dry weight of volumetrically undisturbed 3982 cm^3 sample, % (w/v) means bulk density (dry weight of volumetrically undisturbed 3982 cm^3 sample expressed as a percentage of the weight of the original volume, S.G. peat taken to be 1.0).

‡ T/R = ratio by weight of organic material in trough to that in ridge.

§ Width = spacing between ridge centres.

¶ L = maximum ridge length.

Plr = relative measure of colonisation by *Pleurophyllum hookeri*, adjacent to sample site; 0: absent, 1: rare, 2: common, 3: abundant.

generally more physically variable. This is best reflected in their trough:ridge bulk density ratios which vary from 0.40 to 0.77 (table 1). The ridge peats have bulk densities which approach that of non-patterned blanket mire (sample 1).

Pleurophyllum was mapped as abundant only in samples 6 to 9. Interestingly, these have ridge bulk densities considerably lower than the large-scale wet area features, but trough bulk densities which are much higher. Only these four samples have trough:ridge peat density ratios of 0.8 or greater (table 1). By comparison, *Pleurophyllum* growth is rare around the sites of samples 2a and 11a, with trough:ridge peat density ratios of 0.4 and 0.55, despite the fact that they have ridge bulk densities similar to non-patterned blanket mire (sample 1), which supports abundant *Pleurophyllum*. The relationship between ridge:trough peat density, ridge spacing and *Pleurophyllum* colonisation is illustrated in figure 7.

DEEP SAMPLING

The surface sampling demonstrated distinct differences in bulk density between ridge and trough peats. It remained unclear, however, whether the ridge–trough patterns were merely a recent surface phenomenon or features which persisted at depth, reflecting former mire morphology. Initially, two 900 mm long cores (samples 11a, b) were obtained from a ridge–trough set previously sampled to 300 mm (samples 2a, b). The core was cut into three equal 300 mm sections and dried to constant weight. The results (fig. 8A) showed that the density difference between ridge and trough was preserved to 900 mm. A larger sampler was constructed and four continuous cores (samples 12a, b, and 13a, b) were obtained from two additional trough–ridge sets to a depth of 1500 mm (pl. 1A). Cores from the ridges had a firm texture and retained their shape when removed from the sampler. In contrast, cores from the troughs had less integrity and included brown gelatinous material, possibly indicative of organic colloids. Figure 8B, C shows that the differences in ridge:trough peat densities are preserved, at least to 1500 mm below the present surface.

There is, overall, a symmetry in the patterns between individual ridges and troughs. In samples 12a, b, vegetation density decreases to 600 mm, followed by a rapid increase and possible stabilisation below 1200 mm. In samples 13a, b, a pattern of increasing and decreasing densities is mimicked from 900 to 1500 mm. A general increase in density due to compression might be expected, and it is not clear why these larger vertical variations should occur. Chason & Siegel (1986) described similar variations in

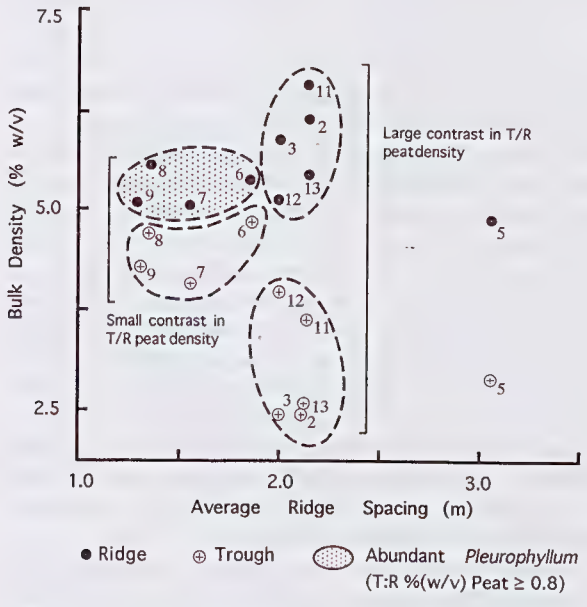

FIG. 7 — Area A: density of the peat below the ridges and troughs, surface to 300 mm depth, expressed as weight (% w/v), plotted against average ridge spacing. Ridge spacing may be taken as a relative measure of wetness, since the wider spaced ridges tend to occur in wetter areas, in particular adjacent to areas of non-patterned mire. As ridges become closer spaced, the ridge and trough peat densities approach each other. Pleurophyllum hookeri *is most abundant on the closely spaced ridges (samples 6–9). While these do not necessarily exhibit the highest ridge peat densities, they do have the highest trough peat densities.* Pleurophyllum *vigour appears to be related to reduced waterlogging and increased water-level regulation, which enhances peat production and reduces the contrast between trough–ridge peat densities. As a result, ridges with the highest peat densities do not necessarily support abundant* Pleurophyllum.

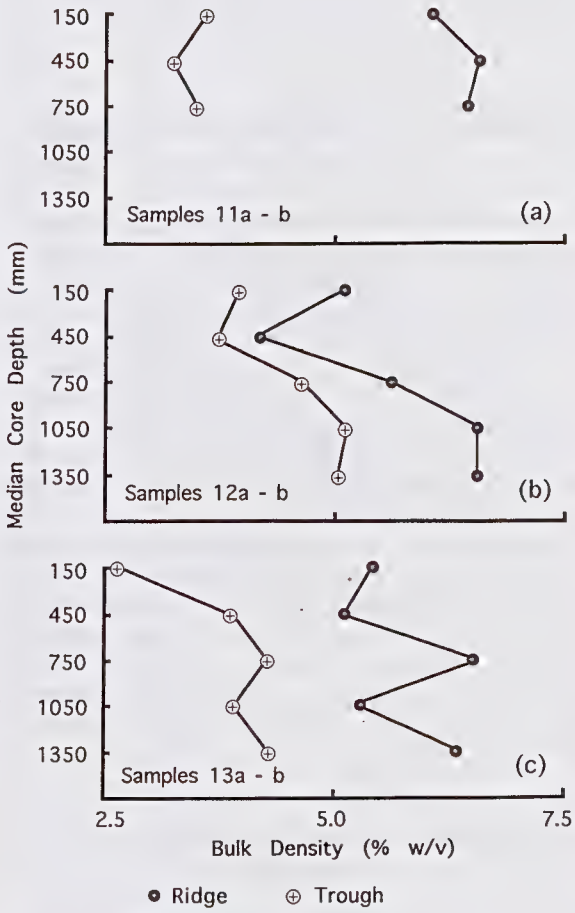

FIG. 8 — Area A: comparison of ridge/trough peat densities, deep sampling profiles. Note that in samples 12 and 13 the vertical variations in density are mimicked in both the ridge and adjacent trough. Depths indicate the median of each 300 mm sampling interval.

bogs and fens which they interpreted as differences in the degree of decomposition. Such variations may represent variations in mire development over time. The reduction in ridge density just below the surface may reflect a condition similar to that occurring in featherbed (Selkirk *et al.* 1990a), where the uppermost layers of the mire float on near surface water lenses.

DISCUSSION

Mire ecologists have long recognised that peat profiles comprise two principal zones. The terms acrotelm and catotelm for the upper and lower horizons were introduced by Ingram (1978). The acrotelm is the aerated surface zone composed of living and undecomposed plant material and within which the water table fluctuates. This is the peat-forming layer within which aerobic bacteria and other organisms break down dead plant material. Its base is generally taken to be the lower limit of water table fluctuation. The main body of the mire is the catotelm, permanently waterlogged and anaerobic, within which biochemical processes proceed very slowly. In a patterned mire the acrotelm and catotelm can be further divided into ridge and trough. The physical properties of all four components will differ. At Handspike, extremes of water table fluctuation are estimated to be about 0.3 m, representing a range from the tops of the ridges to about 0.1 m below the base of the troughs. These figures also are the approximate thicknesses of the ridge and trough acrotelm respectively.

Orientation of the Patterns Relative to the Surface Contours

Apart from their distinctive surface patterns, it was the variation in the slope/pattern orientation which prompted interest in the Handspike mires. All patterned mires form either on very gentle slopes or develop their own sloping surface as a result of peat accretion (Moore & Bellamy 1974). Patterning displays a consistent tendency towards alignment parallel to the prevailing contours (Sjors 1961). It appears probable, therefore, that during their initial development, the Handspike mire patterns were contour-parallel. This accords with their overall orientation, which is roughly parallel to the plateau scarp.

We would expect that the initiation of doming would be accompanied by a tendency for the patterns to maintain a contour-parallel orientation by aligning themselves around the dome. At Area A, quite the opposite appears to have occurred. The patterns have retained their original orientation and now lie, with apparent stability, at angles to the contours. This suggests some advantage in this unusual alignment.

Pattern Orientation and Water Level Regulation

Stability in mires results in the maximum development of both plant associations and peat (Ivanov 1981). Mire plants can tolerate only very limited deviations of the water table. Therefore, in mires, stability requires that water levels be maintained within strict limits of fluctuation and that mechanisms exist whereby fluctuations, under normal conditions, are restricted and, under extreme conditions, are brought quickly back within limits. In a non-patterned mire, this stability is achieved through the vertical distribution of living, dead and decomposing material within the acrotelm where, between the top and bottom, hydraulic conductivity may decrease by several orders of magnitude (Ivanov 1981: 198, Rycroft *et al.* 1975). This has the effect of progressively allowing more or less water to flow as levels rise and fall, and maintaining water levels within a limited range most of the time (Damman & Dowhan 1981).

A patterned mire is more complex and includes a wider variety of plant associations than the simple blanket mire. Stability requires mechanisms which allow different quantities of water through the acrotelm, while maintaining the optimum water table level for each *plant association* (Ivanov 1981). Consider the case where patterns lie at some angle (other than 90°) to the contours. When rainfall is excessive, the water table rises above the surface level of the troughs. Open troughs then provide direct, uninterrupted surface drainage to the edge of the mire. Under these conditions, the troughs act as gutters and are capable of very efficiently shedding large quantities of water from the mire surface. When rainfall is less, the water table falls and troughs become a series of water-filled elongate basins. Drainage at this level occurs in a series of steps, easily and rapidly along the trough as surface water, and then more slowly through the ridge acrotelm (as ground water) and into the adjacent trough as surface water. The rate of water flow is high because most occurs within the troughs as surface flow, impeded only by bottom friction and wind. Flow through the ridges is slower, but the dye tests confirm that the hydraulic conductivity of the ridge acrotelm peats is very high. The flow path is therefore a zigzag series of long (trough) and short (ridge) steps, which overall describe a path oblique to the ideal contour-normal flowlines.

When the troughs cease to contain any surface water, all drainage will occur as ground water. Flow will continue to be biased along the troughs where the near surface acrotelm peats have the highest hydraulic conductivities. With further lack of precipitation, the rate of seepage will continue to decrease, as water levels fall. There will be some critical level which can be sustained temporarily. Lower levels may induce changes in the ridge–trough vegetation. Such a regulation mechanism provides continuously variable water-level regulation, controlled principally by the proportion of standing water in the troughs.

Precipitation on Macquarie Island is recorded on an average of 308 days per year (Streten 1988). Under such conditions, the ability to shed surplus surface water quickly may be advantageous to plants growing on the mire. Meteorological data from the Bureau of Meteorology station (3.5 km east of the field site — fig. 1) suggests that surplus water can be effectively shed over several days. During winter 1990, troughs were consistently water-filled. During heavy rain, water was frequently observed being channelled off the mire. October 1990 was abnormally wet (116.8 mm, monthly average 71.6 mm) and from 1–15 November 1990, 45 mm of rain fell (monthly average 68.2 mm), including 34.8 mm over the period10–15 November, followed by 5 "dry" days (0.2 mm rain on 17 November). Despite the recent abundant rain, the troughs were dry when photographed for this paper, on 20 November (the period 16–23 November was the longest dry spell of the year).

Colonisation of the Patterned Mires by *Pleurophyllum hookeri*

Pleurophyllum appears to be well suited for growth on a mire undergoing vertical accretion. Air canals in the roots vary with the degree of waterlogging (Jenkin & Ashton 1979). Contractile stems maintain the leaf rosettes at the mire surface, while the vertical growth of the stem keeps pace with mire accretion. However, plants growing on the patterned mires are small, compared to those growing on the adjacent and better drained blanket mires. Vigour clearly decreases with increased waterlogging. Jenkin & Ashton (1979) note that plant size may vary by an order of magnitude between poor and favourable sites. Interestingly, however, similar root morphology was displayed by *Pleurophyllum* collected from ridges within the patterned mire and from adjacent blanket mire. In both areas, vertical rhizomes in mature plants were growing to about 0.35 m depth, with decayed tissue extending beyond 0.40 m.

The data suggest that *Pleurophyllum* has colonised the ridges simply because they are drier than the troughs, and preferentially where the contrast between trough and ridge peat bulk density is low (the current study suggests a threshold ratio of 0.8). Ridges with denser peat will have the capacity to maintain water through capillary forces at higher elevations than ridges of less dense peat. Under normal conditions, therefore, the local water table (and waterlogging) will be lower in ridges containing lower density peats.

Similarly, troughs with a higher peat density will release water less easily to ridge capillary suction (when there is no free water in the troughs) than will troughs with lower peat densities. Clearly, ridges with somewhat lower peat density and troughs with higher peat density, when combined, produce conditions where the local level of waterlogging is reduced.

Pattern orientation also appears to be important. Where ridges are contour-parallel, they act as local dams. Surface water is pooled behind each ridge in the form of elongate staircase ponds. Water flow is predominantly through the ridge peats, and the internal ridge water table will be dominated by the higher levels in the upslope trough. In contrast, a ridge which is contour-normal is a local ground water mound, and adjacent water-filled troughs constitute constant head boundaries. During rain, local seepage within such a ridge will not follow the regional flowline down the ridge axis, but instead will be contour-parallel, directly into the adjacent troughs. These ridges will be far better drained than those which are contour-parallel. Higher trough peat densities in the contour-normal patterns may reflect enhanced growing conditions and increased peat production, resulting from better water-level regulation, which occurs where the patterns are most effectively aligned as surface drains. The degree of *Pleurophyllum* colonisation may be related both to the density of the ridge–trough peats and pattern orientation.

Glaser *et al.* (1981) described vegetational changes in patterned mires subjected to altered hydrological conditions. Where the water table was locally controlled by agricultural drainage ditches, strings (ridges) became higher and wider and colonisation by tree species commenced, although the basic string-flark patterns were preserved. Where the mire (and its water supply) was cut by a highway, patterned mire downslope disappeared.

Early Mire Development

The extent to which local basins on the underlying terrace may have influenced early mire development remains speculative. The area underlying the eastern portion of Area A may have been a large pond on the newly emergent terrace. Such ponds are frequently preserved in raised mires, being carried upwards as the mire develops (Moore & Bellamy 1974). Remnant wet areas common in Area A may represent the final vestiges of this feature. The early mire would have been horizontal, initially expanding over the open water, but would have developed its own slope as the mire grew and expanded seaward on the emerging terrace. Initial ponding may have been aided by bolster species such as *Azorella macquariensis* which are considered to be pioneer species (Selkirk *et al.* 1988). Similar ponding aided by *Azorella* can be observed on the recently-emerged terrace between the beach and the raised mire west of Area A. As Macquarie Island continues to rise and further expose the coastal terrace, the raised mire may continue to expand westwards.

The mire in Area A resembles forms described from the Northern Hemisphere, including maritime sloping-plateau eccentric bogs of North America (Glaser & Janssens 1986) and eccentric domed mires of the Baltic region of Northern Europe (Moore & Bellamy 1974). The latter form initially in small basins on sloping ground, frequently within steeper-sided valleys, the peats eventually overflowing the small primary basins. Water supply is greatest up the slope against the steeper valley walls. Here, preferential upward growth competes with gravity acting down slope, resulting in an eccentric dome of peat. Elongated curvilinear hummocks, separated by elongate sinuous pools, develop contour-parallel around the cupola. This bears similarities to the Handspike mires where development may have been initiated in depressions on the sloping marine terrace, the only difference being that early accretion may have been more uniform, with roughly consistently oriented patterns developing prior to late stage doming and eccentricity.

The relationships between slope and pattern spacing provide further evidence that the patterns pre-date doming. Patterned mires and bogs display an inverse relationship between slope and pattern density. In the aapamires of the boreal and subarctic peatlands, the distance between ridges may vary from a few metres on steep ground to greater than a hundred metres on almost horizontal ground (Sjors 1961, Heinselman 1965, Grittinger 1970, Washburn 1979, Foster *et al.* 1983). At Handspike Point, pattern spacings of typically 3 m occur in Area B on slopes which are double to triple those in Area A. In Area B, there is a similarity between terrace and surface slopes, implying a more or less uniform rate of accretion over the mire. This is in direct contrast to Area A, where pattern spacings less than 3 m occur on (comparatively) much shallower slopes. This is the opposite of what would be expected and suggests that, when pattern development commenced, surface slopes in Area A, were probably similar to those currently observed in Area B. The fact that patterns are preserved on the mire surface despite changes in slope and slope orientation suggests either that mire accretion occurs at a more rapid rate than the ability of the patterns to adjust or, as suggested earlier, the new orientations provide unexpected benefits, such as enhanced water-level stability.

Internal Structure and Hydrology

Within mires generally, the acrotelm is very thin compared to the catotelm, and hydraulic conductivities may decrease by many orders of magnitude between the top of the acrotelm and the catotelm (Boelter 1965, Rycroft *et al.* 1975, Ivanov 1981). Water is therefore believed to move much more slowly through the catotelm (Chason & Siegel 1986). Data for a Russian bog (Ivanov [1953], cited in Damman 1986) suggests that only about 1% of total run-off leaves through the catotelm. In contrast, the acrotelm is a thin outer shell, strongly influenced by rapid changes in precipitation, evaporation and transpiration, where water may move rapidly either as surface run-off or as ground water within porous peats. At Handspike Point, the dye tests confirm that gravity drives a general surface water flow over and through the acrotelm peats.

The deep sampling data show that, at Handspike, the surface patterns are preserved in the catotelm and have persisted as the mire has grown upwards. The internal structure of the mire is, therefore, grossly heterogeneous, with multiple, vertically interleaved layers of greater and lesser bulk density (and greater or lesser hydraulic conductivity) aligned at varying angles to the ground water pressure gradient rather like vertical walls or curtains. Ground water flow within the catotelm may therefore be extremely complex. Test pits which probably extended into the upper catotelm suggest that (in the ridges at least) there is significant resistance to ground water flow.

The material sampled at depth comprises roughly 5–6.5 % (w/v) organic matter, the remainder being water. However, not all of this is free to flow as ground water. Moisture which remains immobile and does not seep out under the influence of a small pressure gradient is said to be bound. This includes water which is physically or molecularly bound to organic colloids or other substances, intracellular water within cell cavities in partially decayed plants, and water effectively sealed in single-ended pores and very small capillaries (Ivanov 1981). The low pH waters which are characteristic of such mires retard the breakdown of plant tissue (Moore & Bellamy 1974, Jefferies & Mills 1990). Deep cores taken from the troughs included brown, gelatinous organic material which may have been colloidal in nature. Data from Ivanov (1981) indicated that the total quantity of immobile water in mires may be as high as 100% of dry weight for molecularly bound water and up to 300% of dry weight as water locked within cells. In total, therefore, up to 400% of the dry weight may be immobile water, with the remainder being held by capillary action but capable of being mobilised through gravity or pressure gradients created by the liquid's own weight. The large elastic storativity of peat (Hemond & Goldman 1985) allows mire surfaces to rise and fall as water levels vary in response to rainfall events and the diurnal cycle of evaporation and transpiration (Gilman 1994). Once the capacity of the mire to accommodate excess water is exceeded, water must be shed. Contrasts in hydraulic conductivity between acrotelm and catotelm may explain why surplus water flows preferentially on the surface and relatively little is observed flowing out of the mire around its periphery.

Raised mires are, therefore, an interesting phenomenon, where large quantities of water can be held on stable slopes against the force of gravity. They also represent a dynamic balance between the opposing forces of gravity and upward growth (Moore & Bellamy 1974). As the mire produces more peat, the water table also rises, allowing continued upward growth. At Handspike Point, there is the added complication of a (geologically) rapidly emerging marine platform. Here, there may be a balance, also, between vertical emergence and seaward expansion of the mire. Assuming sea-level stabilisation at 7000 years BP (Adamson *et al.* 1988) and a width of the marine terrace of 500–700 m, lateral emergence of land from the sea at Handspike Point is about 70–100 mm yr^{-1}. There appears to be no reason why the mire should not continue to grow seaward as the island rises. The principal limiting factor is probably water to maintain mire expansion.

The deep sampling suggests vertical non-homogeneity in the peat which is mimicked in the ridges and troughs (fig. 8). These features may represent variations in mire development over time, possibly in response to changing environmental conditions. Chason & Siegel (1986) suggested that vertical bulk-density variations are an indicator of the degree of peat decomposition. Much of the decomposition occurs in the acrotelm and is, therefore, largely influenced by climate. Heinselman (1965) described vertical variations in string bogs from Upper Michigan which are interpreted to be climatically induced. Equally, the observed variations may merely represent the result of taking a thin sample through inherently non-homogeneous material.

Using the sampling techniques described here, it was possible to obtain uncompressed samples only within the upper 1500 mm, representing about one-third of total mire thickness. The data strongly suggest that the patterns are preserved at depth, with a similar orientation to that observed on the surface. Confirmation of these initial impressions will require further subsurface sampling. Deeper sampling would also test whether or not these features remain vertical at depth or show some downslope displacement, implying mire creep. Drury (1956) noted that string bog ridges drag against islands but elsewhere are convex downslope, which he took to suggest some downslope movement. Pearsall (1956) also invoked gravity and downslope movement in the development of mire patterns. Certainly, if the ridge–trough patterns persist to the mire base, it implies that they formed at an early stage, when the mire was very thin, and have been preserved as the mire has grown upwards. Wenner (1947), working on string bogs in Labrador, confirmed that the ridges and troughs retain their separate form to the bottom of the bog. Similar conclusions were reached by Walker & Walker (1961), in their study of patterned Irish peat bogs. However, Thomson (1983) and Foster *et al.* (1983), working on North American string bogs, concluded that patterns developed after the initial establishment of relatively uniform peatland. Ratcliffe & Walker (1958) reached a similar conclusion in their study of patterned raised mires in Scotland. It seems reasonable that, over time and under the influence of varying biotic, climatic, hydrologic and gravitational factors, pattern development may be initiated, maintained or terminated. The interpreted vestigial patterns within Area A may be an example of pattern termination.

Accretion Rates

The steep plateau slopes define the limit of former marine erosion when the sea reached its present high level (Adamson *et al.* 1988). Since then, the island has been subjected to continuous uplift, resulting in a progressive exposure of the raised marine platform (Selkirk *et al.* 1990b). Mires 5 m thick occur within 20 m of the plateau slope base. These mires are presumed to have commenced forming shortly after sea-level stabilisation. Taking this to be 7000 years BP implies mire accretion of about 0.7 m per thousand years.

The total width of the marine terrace around Handspike Point is about 500–700 m, and the thickest recorded mire is 5.9 m. within Area A. This occurs over a shallow terrace depression located about 250 m west of the scarp base. Assuming sea-level stabilisation 7000 years BP and a more or less constant rate of terrace emergence, this point would have been shoreline about 3500–4500 years ago. Here, mire accretion rates may be as high as 1.7 m per thousand years. Assuming an average accretion rate in the central portion of the mire of about 1.0 m per thousand years, the peat samples collected at 1.5 m are therefore estimated to be about 1500 years old.

Wind

It was doubtless the very striking presence of the *Pleurophyllum*, accentuating the ridges, that caught Hamilton's eye during the 1911 AAE. His misnomer "wind rows" has persisted to the present day. The prevailing winds as measured at the meteorological station (fig. 1), are from 290° (Streten 1988), whereas the average pattern orientations in Areas A and B are 050° and 070° respectively. This range in pattern orientation, is roughly parallel to the southwest winds which are associated with an antarctic air flow and are potentially the most destructive to vegetation, frequently carrying snow or ice pellets. Along most of the west coast, such winds are buffered by the plateau. However, at Handspike Point, these winds cross the marine terrace unhindered towards Hasselborough Bay. Feldmark on the plateau includes bryophytes aligned in rows almost parallel to the prevailing wind direction (Selkirk *et al.* 1990a). While wind may not be the principal factor, either in the formation of the patterns or in promoting *Pleurophyllum* colonisation on the ridges, the present pattern orientation may well be advantageous in terms of minimising damage from the most destructive winds.

Comparisons with Other Forms of Patterned Mire

The Handspike mires display similarities to a number of other forms of patterned mire, in particular eccentric and concentric domed mires and string bogs. In overall morphology and physical setting, they are most similar to the Zone 6 eccentric domed mires of Moore & Bellamy (1974). Climate appears to play a significant role in determining mire morphology and forms an integral part of many mire classification schemes, e.g. Moore & Bellamy (1974), Knollenberg (1964), Dewez *et al.* (1984), Allington (1961). Moore & Bellamy (1974) provided climatic diagrams typifying nine principal European mire types. Only eccentric and concentric raised mires and string bogs are characterised by significant ridge–trough patterns. On the basis of climate alone, the Handspike mires do not readily fit any classification. Their physical characteristics, in particular the ridge–trough patterns and domed or raised cross-sections, suggest affinities to the three patterned-mire types noted above. These, however, form under climatic conditions significantly different to those close to sea level on Macquarie Island. These differences are summarised in table 2, the most obvious being seasonally persistent periods of frost. It is the non-patterned blanket mires of the UK and Ireland and the plateau mires of the Baltic region which form, under conditions which more closely approximate those occurring close to sea level on Macquarie Island, characterised by high, persistent rainfall, a restricted temperature range, high precipitation relative to evaporation and no mean monthly temperatures less than 0°. It is, therefore, probably little coincidence that non-patterned blanket mires are common on the wider portions of the raised marine terrace from Handspike Point south to Aurora Point and within the Green Gorge basin on the central east coast. Hence, the patterned mires at Handspike Point appear to be anomalies

TABLE 2

Climatic Comparison between Sea Level on Macquarie Island and Sites of Principal Mire Types in Northern Europe*

Comparison between sea-level climate on Macquarie Island and climatic criteria associated with the principal mire types of northern Europe. The Handspike patterned mires display physical similarities to eccentric raised mires but form under climatic conditions similar to those associated with the non-patterned European plateau and blanket mires, i.e. characterised by higher rainfall and no minimum monthly temperatures below freezing. The Macquarie patterned mires, therefore, appear to be an anomaly, and this may in part explain their very limited distribution on the island.

	Macquarie Is	Non-patterned European		Patterned European Mires		
		Plateau	Blanket	Concentric	Eccentric	Aapamires
Mean Temperature (T)	4.7	9.4	10.2	6.3	1.8	-1.2
Months with Mean T <0	nil	nil	nil	5	6	8
Mean Annual Rainfall	903	838	1439	583	559	520
Maximum Monthly Rainfall	90	85	110	70	80	75
Minimum Monthly Rainfall	60	50	95	35	30	20

* Macquarie Island data from Bureau of Meteorology (1975), National Parks and Wildlife Service (1987) and Streten (1988). European data from Walters & Lieth (1960) and Moore & Bellamy (1974).

which may have formed in response to slightly different environmental conditions. Climate, however, does not appear to have been a major factor. Palynological data (Selkirk *et al.* 1988) suggest that the climate on Macquarie Island has been stable for the past 6000 years. The most obvious factor may be increased ground water flow, sufficient to sustain the development of a raised mire. The width of the raised marine platform may also play a role. The terrace reaches its maximum widths of about 1100 m and 700 m at Eagle Point and Handspike Point respectively (Selkirk *et al.* 1990b). Elsewhere, the terrace may simply be too narrow, too steep or the ground water supply inadequate to support the development of raised mires, which are typically several square kilometres in area, and whose development is constrained both by area and water supply (Moore & Bellamy 1974).

SUMMARY AND CONCLUSIONS

Patterned mires at Handspike Point occur in two areas and display a more or less consistent NE–SW alignment. Patterns are now aligned parallel and at angles to the contours. Bulk density measurements at depth suggest that this alignment has prevailed over much of the mire's history. In Area B, patterns are roughly contour-parallel and display characteristics typical of patterned mires described elsewhere. Ridges are preferentially convex down slope and act locally as dams, impeding surface water flow. In Area A most of the patterned mire is aligned contour-normal. Rather than exhibiting degraded or chaotic patterns (as one would expect if contour-parallel patterns were re-establishing), the present patterns appear to be in dynamic equilibrium with the growing mire. Patterns are best developed where the troughs are interconnected, permitting surface water drainage. Here, patterns exhibit higher trough peat bulk densities and ridges more readily colonised by *Pleurophyllum hookeri*.

There is an extensive body of literature which suggests that mire patterns will tend towards a contour-parallel alignment. Where doming occurs in raised mires, for example, patterns form and realign themselves to maintain a concentric orientation around the cupola. At Handspike Point, the apparent vitality of the contour normal patterns suggests advantages in this orientation. Factors and causes are doubtless complex and almost certainly interrelated. The trough orientation permits large quantities of surplus water to be shed rapidly. Ridges are less waterlogged by virtue of being local ground water mounds (rather than dams). Water levels fluctuate less, thereby enhancing conditions for plants growing on both the ridges and troughs. The present orientation of the patterns also minimises damage from the most potentially destructive winds. Mire accretion may simply be occurring more rapidly than the ability of the patterns to adjust, but a more holistic approach suggests that the new orientations provide a number of unexpected benefits, most particularly enhanced water-level stability.

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NOTES ON THE GEOLOGY AND GEOMORPHOLOGY OF DE WITT ISLAND, SOUTHWEST TASMANIA

by Grant Dixon and Ian Household

(with two text-figures and four plates)

DIXON, G. & HOUSHOLD, I., 1996 (30:vi): Notes on the geology and geomorphology of De Witt Island, southwest Tasmania. *Pap. Proc. R. Soc. Tasm.* 130(1): 67–73. Parks and Wildlife Service, GPO Box 44A, Hobart, Tasmania, Australia 7001.

De Witt Island, off the south coast of Tasmania, is composed of a folded succession of turbiditic silstone, sandstone and conglomerate, at least 450 m thick. It is probably a correlate of the Mid to Upper Cambrian Ironbound Group. Folds are upright, open to tight, and at least two generations are indicated. The broad-scale geomorphology of the island is controlled by the direction of storm waves which have eroded nearly vertical cliffs up to 340 m high on the south shore. Many sea caves are found at the base of the cliffs, particularly on the west and south coasts. Cliff retreat has progressively captured the headwaters of the island's two perennial streams. Fluvial processes, controlled by both lithology and structure, but also showing possible influence from interglacial and glacial stages, have shaped the interior of the island for a long period. Aeolian processes have deposited sand sheets in the island's central basin. Some well-developed pseudokarst systems, including sinkholes, caves, underground drainage and airflows, are related to large rotational slumps on the island's south coast.
Key Words: Cambrian sediments, turbidites, coastal stream capture, mass movement, pseudokarst, Tasmania.

INTRODUCTION

De Witt Island is the largest of the Maatsuyker Group of islands, all of which are part of the Tasmanian Wilderness World Heritage Area. It lies some 6 km south of Louisa Bay, on Tasmania's south coast. The island is broadly triangular in shape, some 3 km across and 6 km^2 in area, with cliffs (250–300 m high to the south) on all sides except a part of the central north coast. The highest parts of the island are located very close to the south coast, and enclose a north-facing basin. The island's 340 m summit is located very close to its southermost point.

The island is almost completely forested. Rainforest occurs in the major creek valleys, open mixed forest occurs throughout the north-facing basin, and dense tea-tree forest and wind-pruned coastal scrub occur in the northwest and far west of the island. Tussock and associated vegetation occurs on several very steep coastal slopes in the northwest. Dense, tall bracken fern blankets an area around the small northern estuary, an area which has been repeatedly burnt in the past (White 1981). However, the large size of many of the eucalypts, presence of rainforest vegetation and lack of evidence of charcoal attest to a long period without fire for the eastern half of the island.

Forest soils in the unburnt part of the island are deep, brown and peaty, with a thick litter layer in most areas. The burrowing activities of various seabirds have significantly affected soil development in several areas, particularly around the estuary and on steep slopes in the east, south and northwest.

Bedrock outcrop is generally poor in the island interior. However, exposure is excellent and near-continuous around the coast, although very steep slopes and thick coastal vegetation restrict access. No earth scientist has previously made on-ground observations on De Witt Island.

Previous Geological Observations

Lord (1928) noted white conglomerate or quartzite on Baldy Point, the northeastern tip of De Witt Island. White (1981) reported schist and shale from the west coast and micaceous sandstone from the north coast. The 1:250,000 geological map compiled for the region (Williams & Corbett 1977) shows De Witt Island as undifferentiated Precambrian metamorphic rocks.

Banks (1993) summarised the available geological observations of De Witt Island and described two rock samples, a siliceous conglomerate and a thinly bedded quartzite, collected by Nigel Brothers. He concluded that the De Witt Island rocks most closely matched the "Younger Precambrian" (Spry & Baker 1965) rocks at Bathurst Channel, but that there was some similarity with parts of the sequence on the Ironbound Range.

The western islands of the Maatsuyker Group (Maatsuyker, Walker and Flat Witch Islands, Needle Rocks) are composed of polydeformed Precambrian rocks, mainly schists (Banks 1993), but the thick bedding visible in the southern cliffs of De Witt Island, and also in Flat Top and Round Top Islands, indicate that these islands are distinctly different.

BEDROCK GEOLOGY

Three associations have been identified on De Witt Island —a massive siliceous conglomerate, a conglomerate–siltstone association and a micaceous siltstone. A geological map of De Witt Island is shown in figure 1.

Massive Conglomerate

Massive conglomerate occurs as thick, subvertically dipping units in the northeast of De Witt Island, outcropping conspicuously as a broad rib and bluff above Baldy Point.

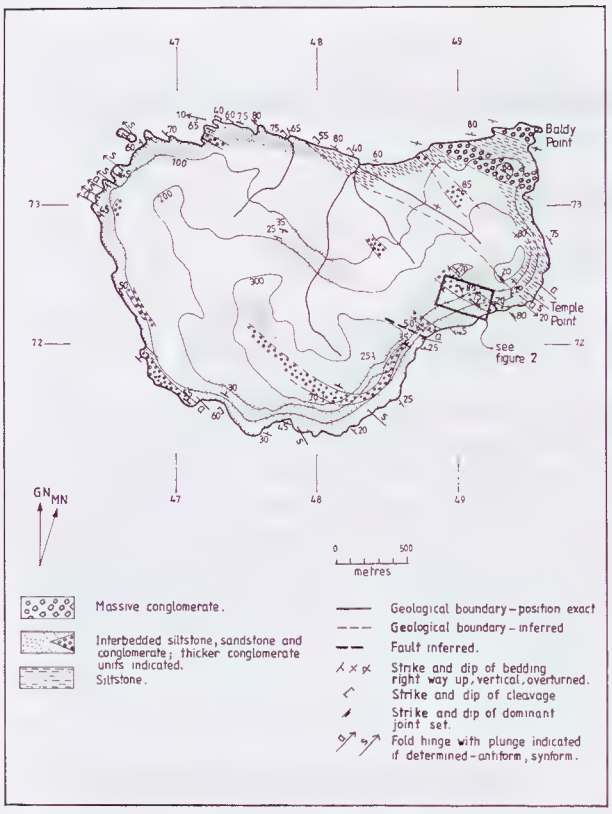
Baldy Point
Temple Point
see figure 2
GN MN
0 500
metres
Massive conglomerate.
Interbedded siltstone, sandstone and conglomerate; thicker conglomerate units indicated.
Siltstone.
Geological boundary – position exact
Geological boundary – inferred
Fault inferred.
Strike and dip of bedding right way up, vertical, overturned.
Strike and dip of cleavage
Strike and dip of dominant joint set.
Fold hinge with plunge indicated if determined – antiform, synform.

FIG. 1 — Geological map of De Witt Island. The geomorphological map (fig. 2, see p. 72) encompasses the area indicated by the box.

The rock is a generally coarse, white, siliceous conglomerate. It is clast-supported, consisting mostly of subrounded clasts of quartzite and quartz schist, the latter tending to be the more angular. Most of the clasts are somewhat elongated (a:c = 1.5–3) and range in size from 10–80 mm maximum dimension. Rare larger (0.15–0.20 m) subangular quartz schist clasts occur. The matrix consists of sand and fine pebbles. Separate beds are not discernible at outcrop scale, but a clear imbrication is apparent.

This unit is considered here separately from the conglomerate units within the finer grained succession, discussed below, on account of its more massive nature, larger modal clast size and clear imbrication.

Interbedded Siltstone and Conglomerate

An interbedded succession of siltstone, pebbly siltstone or sandstone and conglomerate comprises most of island (pl. 1). However, within the interbedded succession, extensive parts tend to be dominated by a particular lithology. In particular, there are sections in which conglomerate comprises a stratigraphically significant part of the succession (fig. 1). Conglomerate also occurs as isolated beds within finer grained parts of the succession. In broad terms, siltstone–sandstone and fine sandstone–conglomerate associations are apparent and may be able to be separated with more detailed mapping.

The siltstone is grey (rarely greenish) and laminated or thinly bedded, generally <5 mm thick. Quartzitic pebble beds or lenses, up to 0.1 m thick but usually much less, occur sporadically, and rare subrounded quartzite clasts

PLATE 1

Interbedded conglomerate (light coloured) and quartz siltstone (dark) east of Temple Point. The entrance to a relict sea cave, some 30 m long and 5 m above present sea level, lies behind the debris fan at right. Note person (circled) for scale, bottom right.

30–40 mm in diameter have also been noted. Sandstone beds are dark grey, quartz-rich and can be somewhat indurated. The lower few centimetres of sandstone beds, particularly where they overlie conglomerate, tend to be pebbly — perhaps a poorly developed basal grading. At DM478735, several beds of greenish pebbly siltstone are interbedded with grey siltstone, with beds 0.2–0.5 m thick. Pebbles are quartzitic, rarely feldspathic and subangular. Further west, near DM474736, 0.3 m thick graded pebbly sandstone beds or lenses are interbedded or intercalated with siltstone which contains rare subrounded quartzite pebbles. Pebble content of beds varies laterally in many places.

The conglomerate units are white and siliceous, with clasts consisting of quartzite, quartz and rare quartz schist. The rock is generally matrix-supported but is clast-supported locally. The clasts are subrounded to subangular, 5–40 mm maximum dimension (modal size varies at different localities) and elongate (a:c = 2). Cobble-size clasts occur locally or in some beds, and in these areas the conglomerate tends to be clast-supported (e.g. west of Temple Point and at DM489724). The conglomerate comprises massive beds, rarely displaying internal lamination or imbrication, but is sometimes size graded (to pebbly sandstone at DM493725) from 0.5 to more than 5 m thick. At DM474736, a 1.5 m thick graded conglomerate unit lenses out along strike within 10 m.

The succession in the northwestern part of De Witt Island contains less conglomerate, consisting mainly of interbedded grey siltstone and dark micaceous sandstone with rare pebbly (quartzwacke?) horizons.

Load casts are apparent where silty or sandy beds underlie some conglomerate horizons, well exposed at DM493723. In the same area, a coarse siltstone bed displays upwardly disrupted laminae suggestive of fluid escape. These structures are regularly spaced, with a 0.4 m separation, throughout the 25 m long exposure of this bed.

A succession some 450 m thick is exposed in the southern cliffs, below the island's summit, where about 200 m of predominantly sandstone–siltstone is overlain by pebbly sandstone or conglomeratic units.

Siltstone

This unit is exposed as a very steeply dipping succession along much of the north coast of De Witt Island, particularly around the small estuary and main landing place. Whilst described here as a distinct rock unit, it is likely that the siltstone is merely a more consistently pelitic part of the previously described unit, with no conglomerate lenses or beds noted.

The rock consists of micaceous siltstone and sandstone, with rare granule sandstone. Many beds are finely laminated (1–3 mm thick), with wavy lamination common, and truncated cross lamination developed in some sandier beds. Partial Bouma sequences (ACD, ABCD, BCD), 0.20–0.25 m thick, can be discerned in several areas. Convolute laminae and "dish" or fluid escape structures occur in several discrete siltstone beds.

Closures exposed in the eastern cliffs indicate that the siltstone unit has been tightly folded, at least in part. The unit may therefore be as little as 200 m thick, with parts of the succession exposed along the north coast repeated.

Age and Geological Relationship

Given the geographical proximity, the rocks of De Witt Island can be correlated with the Ironbound Group (Findlay 1994) on lithological grounds. The massive conglomerate is similar to the upper part of the Havelock Bluff Formation, and the interbedded siltstone, sandstone and conglomerate sequence has affinities with the Lousy Bay Formation. The rocks of Flat Top and Round Top Islands, which have been both observed by one of the authors (GD) and described by Banks (1993), are similar to those described herein and are likely also to be correlates of the Ironbound Group.

The Ironbound Group unconformably overlies poly-deformed Precambrian rocks (which also occur on Maatsuyker and other islands southwest of De Witt Island). It is conformably overlain by Denison Group siliciclastics and is considered to be Mid to Late Cambrian in age (Findlay 1994).

No fossils were found in any of the rock units on De Witt Island. However, at DM478728, a single rounded feldspar porphyry clast, some 0.25 m in diameter, occurs in laminated quartzitic siltstone. The clast, comprising altered feldspar and lesser quartz in a fine, greenish groundmass, is similar to Cambrian volcanic units now exposed in western Tasmania. Findlay (1994) observed presumed Cambrian volcanic material in rocks of the Ironbound Group and noted that this supported a Mid to Late Cambrian age for the Group. A similar conclusion is indicated for the De Witt Island succession.

Environment of Deposition

Findlay (1994) considered the Ironbound Group to be a proximal fan sequence. The lithologies and range of sedimentary structures which occur in De Witt Island indicate rapid deposition, largely from turbidity currents and debris flows, with occasional fluidised flow. Conglomerate lenses which occur within the sandstone–siltstone succession probably represent debris flows within channels. This interpretation is consistent with the De Witt Island rocks comprising part of the Ironbound Group.

Siltstone exposed on the north coast of De Witt Island may be a more distal part of the sequence, compared with the sandstone–siltstone–conglomerate succession which comprises the southern parts of the island. This would suggest transport from the south or southwest, consistent with palaeocurrent directions inferred from observations of cross laminations exposed on the north coast, and also with Findlay's (1994) observations on the Ironbound Group in the Ironbound Range area.

Geological Structure

The De Witt Island succession has been folded, with a zone of relatively tight folds bisecting the island east–west, with very open folding occurring further to the south and very steep dips (but no apparent closures) to the north. This structural variation may relate partly to lithological differences, with the southern part of the island composed of predominantly coarser grained units. However, at DM474736, on the north coast, tight folding in sandstone and siltstone gives way abruptly to consistently steep dips to the north with no apparent discontinuity or local lithological change.

Folds are generally upright to gently inclined and gently plunging, with axes trending east–west to northwest–southeast. Fold style ranges from open to tight, almost isoclinal locally, with no significant differences in axial plane orientations. These differences appear to relate mainly to lithological variations, with open, parallel folds typical where coarser grained and conglomeratic units occur, tight similar folds observed in the finer grained and pelitic units, and chevron-style folds evident in part of the turbidite succession exposed on the west coast. Similarly, fold wavelengths range from 2–3 m to almost 50 m over a distance of 200–300 m along the northwest coast, the larger scale folds occurring in coarser lithologies. This lithological control on fold style and scale can result in distinctly disharmonic folding, as in the excellent coastal exposure at Temple Point, where open folding in thick conglomerate beds gives way to very tight, upright folding

PLATE 2

Folding in conglomerate and siltstone on southeast coast, with very steep dips in siltstone at left, very open concentric folds in interbedded conglomerate–siltstone to right. The light-coloured ribs are siliceous conglomerate strike ridges. The major pseudokarst area occurs on the plateau at top left and terminates, to the east, against the conglomerate strike ridge and pinnacle.

in pelitic beds without apparent faulting or discontinuity (pl. 2). Folds in the west of the island plunge gently westwards, whereas those in the east plunge to the east or southeast. Later gentle warping of the island succession along a north–south axis is therefore indicated.

A structural foliation, which can be seen to be axial planar to folding near DM474736, occurs but is well developed only in the pelitic units exposed along the north coast. Here, the foliation dips moderately to steeply southwest, intersecting bedding at a high angle, thus giving rise to the jagged, sharp nature of coastal outcrops and controlling their alveolar surface weathering. Banks (1993) noted the development of muscovite flakes with two orientations, differing by 50°, in a "quartzite" sample obtained from the north coast. It seems likely that these orientations relate to bedding and the aforementioned structural foliatios.

Thin, irregular quartz veins and segregations occur in several localities, usually at a high angle to both bedding and cleavage. They may indicate high strain or hinge zones, but their occurrence is not ubiquitous.

Jointing is not generally well developed but is apparent in some of the more massive conglomerate units. Near Temple Point, widely spaced (0.5 m) subvertical joints are apparent in thick conglomerate beds, but joints are closely spaced and poorly developed in the thin sandstone and siltstone interbeds. Here also, the surface of a conglomerate dip slope shore platform is spectacularly dissected, grike-like (although the rock is not calcareous) along the joint sets.

GEOMORPHOLOGY AND CAINOZOIC DEPOSITS

The landforms of De Witt Island are controlled, on the broadest scale, by a combination of lithology and rock structure, geomorphic processes and inheritance of previous landforms. Whilst the fluvial pattern of the island and internal slope angles and orientations are strongly (though not completely) influenced by differential erosion of strata of varying resistance and by the presence of zones of structural weakness, the overall shape of the island, the orientation of its cliffs and nature of its coastal deposits result from the overriding of geological controls by powerful coastal processes. These are, in turn, controlled by climatic patterns influencing average storm wave directions.

In some instances, both geological and contemporary geomorphic controls on landforms are overridden by inheritance of patterns established during different climatic or eustatic conditions, which operated earlier in the Cainozoic. For example, at times of glacial low sea levels, the regional base level of erosion would have been well below the present ocean floor in the vicinity of the island (Banks 1993), and all marine processes surrounding the island would have ceased. This would have left only fluvial (and periglacial?) processes operating on that part of the southern highlands which, during interglacials, became isolated by rising sea levels. It is argued later that the main stream pattern on the island is due more to inheritance than to structural control or present-day geomorphic processes.

Cainozoic deposits on the island result from many of the more usual geomorphic processes operating on oceanic islands. These include coastal, fluvial, aeolian, mass movement and weathering lag deposits. More unusual deposits are chemical sediments deposited in sea caves as a result of solutional processes. No dating of the deposits was undertaken, but some scope exists for dating and palaeogeographical analysis of relict aeolian features, raised beach deposits and speleothems.

Coastal Deposits and Geomorphology

The most widespread Cainozoic deposits on the island are coastal deposits consisting predominantly of cliff-foot talus derived from erosion by storm waves. Most are active at present. These large angular deposits are found mainly on the exposed south and west coasts and are derived predominantly from collapse after erosion at the bases of cliffs. The prevailing southerly and westerly direction of storm waves is, at present, by far the most important control on the gross morphology of the island, being more influential than geological controls or inherited features.

It is likely that, during glacial low sea levels, the part of the southern highlands which is now De Witt Island would have attained a more rounded profile than at present, as only fluvial and, possibly, periglacial processes (indicated by fossil slope deposits consisting of predominantly angular clasts at DM 470734) would have been operating. However, during the marine transgressions, and particularly the most recent, the enormous erosive capacity of the Southern Ocean has led to the undercutting of that rounded topography to produce a markedly asymetrical profile, with near vertical 300 m high cliffs facing the predominant southerly swells.

This continual undercutting and destabilisation have initiated mass movements of the upper cliff sections in three main ways. Firstly, massive rotational slumps are common on the south coast, on the well-vegetated cliff tops to the west of Temple Point. Although no recent scars are visible, it is likely that these slumps have contributed some of the more massive boulders to the cliff-foot deposits. These large slump areas are associated with some interesting pseudokarst features described below.

Secondly, and more commonly visible today, smaller individual landslides, consisting of boulders up to 1 m in diameter, are initiated from vegetated mid-cliff sources, probably greatly aided by waterlogging and other fluvial processes following heavy rains. Evidence of at least three major, recent landslides is found on the south coast, involving vertical disturbance of over 200 m. It is likely that these landslips are reworking older, angular slope deposits originally emplaced during glacial stages. Although obscured by dense vegetation on the southern cliffs, fossil slope deposits containing predominantly angular clasts may be seen from the sea on the northwest coast, where wind pruning has prevented dense vegetation from establishing.

On the west coast, the third major style of breakdown is illustrated. The cliffs here are, in contrast to those on the southeast coast, predominantly unvegetated and almost perpendicular, but are not nearly as high. Breakdown appears to occur through a process of mass failure of entire faces rather than slumping or discrete landslips.

Although relatively small cliffs occur on the very northwest and northeast shores, the majority of the north coast consists of steep slopes fashioned more by fluvial processes than through mass movement initiated by wave action. Where cliffs do exist, they are more common above sea cave entrances, where undercutting has progressed at a faster rate.

Many reasonably extensive sea caves are found around the island, although weather conditions allowed only a few to be examined in detail. Both active and relict caves are present, some being found up to 3–5 m above present sea level. Sea caves are most common on the island's northwest shore, where storm waves may most effectively exploit the northwest–southeast orientation of the bedding and structure. All of the sea caves are essentially structurally controlled, although in many cases collapse has significantly modified the primary form. Many caves are found in fold hinges, in areas of relatively more erodible rocks and subvertical dips, with roofs and walls composed of more competent units.

Most sea caves contain well-rounded boulder deposits, although in many of the caves examined they were covered by extensive areas of roof collapse. Less collapse is evident in the caves of the sheltered north coast; the large cave at DM487733 possesses an almost complete primary form, with a floor composed entirely of rounded cobbles. One cave examined to the west of Temple Point contained sparse but reasonably massive ferruginous stalactites, as well as a large mass of coralloid speleothems on a conglomerate wall. Their composition has not been determined.

Narrow shore platforms are present on the north shore, although the harder lithologies, in general, remain as steep ridges dividing planed areas of softer rock. Some interesting erosional micro-features are present on these surface,s including large, knife-edged erosional remnants, where thin beds of hard strata are left following erosion of surrounding weaker beds, and dendritic channels, which have been deeply cut by ocean swells in well-jointed conglomerate (pl. 3).

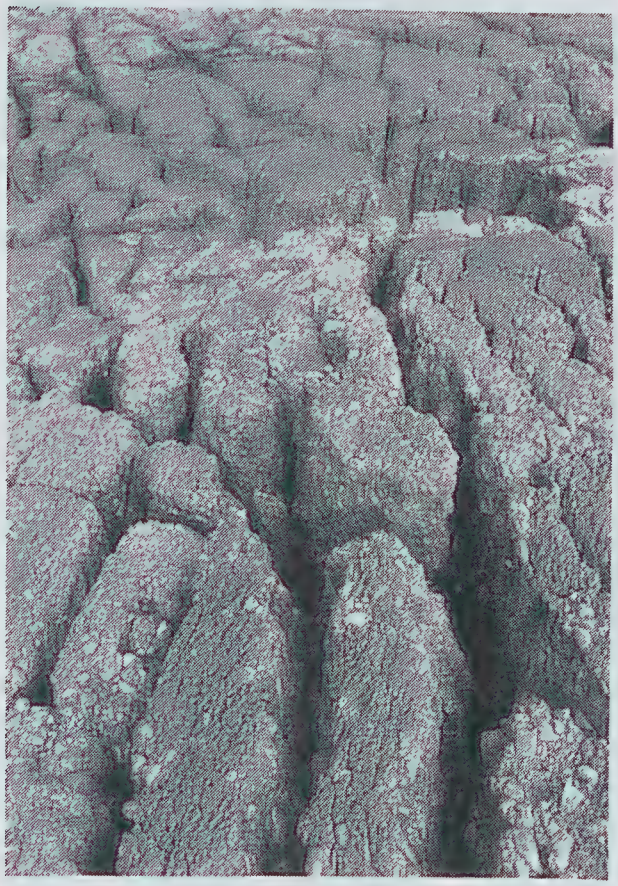

PLATE 3

Wave-excavated joint fissures in conglomerate, exposed in shore platform at grid reference 494724. The width of the field of view, at base of photo, is approximately one metre.

Small, active boulder beaches are most common at the mouths of sea caves on the north shore and at the heads of more sheltered gutters. An apparently fossil cobble beach deposit is found at DM476736. This deposit appears to be approximately 2 m above an active beach and consists of clasts of rounded to subrounded, locally derived rocks in a clayey matrix.

Although the sea bed to the north of the island is essentially sandy, nowhere are the submerged shelfs shallow enough to allow the buildup of sandy beaches. Small sand pockets are found at the mouths of the island's main stream systems at DM 483733 and DM 478737.

Aeolian Processes and Deposits

Aeolian features are common along the north coast. It is assumed that aeolian features on the other, more exposed coasts are soon obliterated by more powerful coastal processes. To some extent, wind appears to be contributing to the erosion of weathered material and unconsolidated deposits along the sparsely vegetated northwest shore. Strong, salt-laden winds have prevented the development of more than a sparse vegetation cover, which here consists of stunted heathland and, on the steeper slopes, of a discontinuous cover of tussock grasses. Much weathered siltstone is removed by wind, and alveolar weathering has resulted from salt crystallisation on exposed, soft rock faces below overhangs, where runoff is not present.

Large sand deposits are a feature of the north-facing basin. They do not form dunes, consisting more of sand sheets overlying fluvially eroded and weathered siltstones. These are now fossil features generally well consolidated by thick growths of bracken fern. They are exploited by Fairy penguins and Short-tailed shearwaters as burrowing sites. This activity incorporates a large amount of fern breakdown in the sand, producing deep organic A horizons in the soil profile. It is possible that this extensive burrowing activity may have reduced any primary dune forms to the more continuous surface present today. It is likely that these deposits were emplaced during Late Pleistocene–early Holocene times, when banks of sand to the north of the island were mobilised and exposed by fluctuating sea levels. Similar sand sheets and bioturbation effects on soil physics and chemistry are described by Pemberton (1991) from nearby Maatsuyker Island.

Fluvial Landforms and Deposits

De Witt Island is the only one of the south coast islands to possess perennial streams. Two main stream systems are found there, although each contributes only a few tens of litres/sec discharge even at peak flow. The water is particularly deeply stained by organic complexes, derived from long-unburned forest peat soils and as a result of drainage from extensive rookeries of seabirds, which are continually incorporating organic materials into quickly draining sandy soils by burrowing activities.

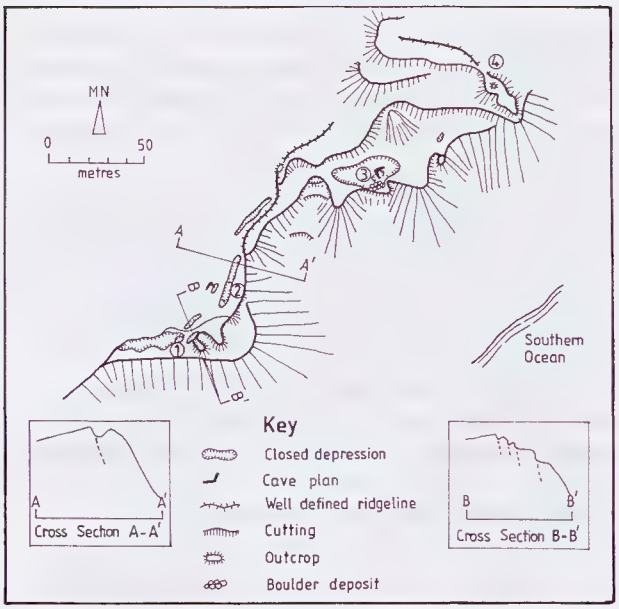

FIG. 2 — Geomorphological map of pseudokarst area, located at grid reference 489726; 1 to 5 refer to sites described in the text.

The main drainage system forms a fan-shaped basin on the island's eastern half. The largest stream roughly bisects the island. In its upper reaches, its course is structurally controlled, running parallel to the strike of the bedding and exploiting the axis of a synclinal structure. A third of the way down, it departs this trend to flow perpendicular to the strike over a series of cascades and small waterfalls, following no obvious structural control (no major joints or cleavage appear to run in this NNE direction). It is likely that here some form of landform inheritance plays a role in directing the stream's course, possibly related to stream capture, following lowering of regional base levels during one of the Pleistocene glacials. This orientation is mirrored by the other drainage system located further west on the island; its direction is probably controlled by similar circumstances.

The two tributaries of the main drainage system exhibit classical structural control, exploiting zones of comparatively soft siltstone between emergent conglomerate ridges, flowing parallel to the strike and joining the main stream near its mouth on the coast.

The drainage system shows remarkable evidence of being rapidly truncated at the headwaters, due to the encroachment of coastal cliffs from the south — a most extreme form of stream capture. At present, the drainage divide for most of the southeastern part of the island is, in fact, the clifftop. A series of ridges and cols along the skyline marks the locations of former valleys and interfluves which no longer carry drainage, as the cliff is more rapidly undermined by coastal processes than fluvial systems can initiate southerly flowing stream systems. Each minor ridge appears to be controlled by the presence of coarser grained rocks (conglomerate or pebbly units in the sandstone or siltstone units), whilst the cols are generally in softer siltstone.

Before debouching to the sea, the streams converge to a point on the central north coast where a wide band of comparatively soft siltstone is found. The central basin is focussed on this soft rock; its contact with harder sandstones and conglomerates marks a considerable lessening of stream gradient. Small alluvial deposits are found along the margins of streams where they enter the basin, but most alluvial material appears to have been covered by the aeolian sand sheets.

The mouth of the stream consists of a small tidal inlet, which appears to be a very small example of a drowned valley cut during glacial low sea levels. Soundings at the mouth of this inlet indicate the valley continues northwards below present sea level.

Although exposure is poor, there appear to be very few significant angular slope deposits in the interior of the island. There are, however, large amounts of lag material, generally subrounded clasts derived from conglomerates, present on the slopes and broad ridge crests. Soils appear to be quite thick, especially on valley slopes and bottoms, and contain a large proportion of organic matter. This suggests that chemical weathering and fluvial processes have played the major role in denudation of the interior of the island, away from the influence of coastal processes.

Pseudokarst

Figure 2 illustrates an area to the west of Temple Point, where an unusual suite of mass movement and pseudokarst features is found. This is the better developed of two such sites on the island, consisting of closed and partly closed depressions, fissure caves and boulder caves, subsidence terraces and large rotational slump features. The other site, at DM 484719, contains closed depressions and subsidence terraces also related to large rotational slump blocks (pl. 4).

First impressions of this area suggested that it was, in fact, a true karst area and led to early speculations that there may be dolomite on the island. Large closed depressions, of similar size and form to truly karstic depressions, and cave entrances with significant air movement more closely resemble the outward form of true karst than those in similar pseudokarst areas more commonly asssociated with dolerite slump blocks (e.g. Sharples 1995).

The Temple Point site is found in a sandstone and conglomerate unit bounded to the northeast by a band of coarse siliceous conglomerate (fig. 1). The pseudokarst is located at an altitude of approximately 250 m, in the head

PLATE 4
Closed pseudokarst depression, about 10 m deep, at grid reference 484719.

of a small, very steep valley. It appears that mass movements down this valley associated with minor fluvial erosion have destabilised an arcuate area at the valley head, initiating a series of rotational slumps whose axes are parallel to the cliffline at that point. Therefore, whilst the valley floor trends structurally in a northwest–southeast direction, rock structure has played only a minor role in determining the orientation of the individual slump blocks.

The direction of movement has been controlled more by the immediate relationship of the slump block has with the arcuate valley head; the partings between individual blocks and the main rock mass are likely to be controlled by a form of unloading joint more associated with the geomorphic history of the locality than with existing bedding, joints and cleavage planes.

The cross sections marked on figure 2 indicate the broad nature of the local topography. At B–B' four separate subsidence terraces are found, the upper two showing marked rotation, with the landward section of the terrace treads forming elongated closed depressions along the slip surfaces (site 1). At A–A', a major terrace containing two strongly draughting holes is backed by a single, slightly elongated closed depression with a cave of humanly enterable dimensions (site 2). This cave is penetrable to a depth of approximately 10 m and also issues a strong draught. The cave is developed in a wide fissure at the contact between the slump block and *in situ* bedrock. It contains many angular boulders, probably dislodged during the slumping process, which are partially infilled with a matrix of fine silt derived from surface wash. At its furthest point, the cave disperses into a boulder maze with no human access; however, the strong draught indicates the likelihood of a large air volume amongst breccia along the slump plane.

Site 3 is the best developed pseudokarst topography on the island, containing a 10 m deep, closed depression leading to a 15 m deep fissure cave. The cave shows evidence of fluvial modification of the collapse block walls and contains stratified sediments, indicating significant water flows from the internally draining catchment. It also issues a strong draught, but it too becomes impassable, due to boulder fills. The cave contains a dark zone with many invertebrate species, including cave crickets and at least three species of spiders. *Hickmania troglodytes* (Tasmanian cave spider) was not found anywhere on the island, but a smaller, though similar species also building a horizontal sheet web inhabits both caves. Also common is a species of woolly centipede, a life form not yet described from any Tasmanian cave (S. Eberhard, pers. comm.). Approximately 50 m northwest of site 3, a 10 m long boulder cave is found passing through a short spur, an erosional remnant of a subsidence terrace.

Bounding the entire pseudokarst area to the northeast, a prominent strike ridge of competent, subvertically dipping conglomerate forms a major cliff leading almost vertically to sea level (Site 4). No slump blocks have formed in this unit, and it appears that the entire pseudokarst area is backed onto it, the contact forming the limit of slump activity in this direction. A similar band approximately 200 m to the southeast forms the boundary on that side.

DISCUSSION

The succession of folded clastic rocks occurring on De Witt Island, a probable correlate of the Ironbound Group (Findlay 1994), extends southwards the extent of Cambrian rocks in Tasmania. The continuous coastal exposures of these rocks, both in narrow shore platforms and high cliffs, are amongst the most spectacular in Tasmania. A proximal fan depositional environment is inferred for the succession; given this and the predominantly siliceous clast lithology, it is interesting to speculate on the source of the single cobble-size, rounded clast of ?Cambrian volcanic porphyry noted in laminated quartz siltstone.

In broad terms, the geomorphology of the island very clearly illustrates a process of ongoing stream capture through the encroachment of coastal cliffs on the headwaters of a fluvial system. This style of stream capture and the attendant effects on surrounding landforms and processes are not well illustrated elsewhere in Tasmania. Whilst pseudokarst features are quite common below dolerite escarpments in eastern Tasmania and generally larger, the highly integrated nature of closed depressions, caves, fluvial and atmospheric processes make the De Witt Island examples amongst the best developed in the state.

ACKNOWLEDGEMENTS

Neil Smith, skipper of *Wild Wind*, is thanked for providing transport to and from De Witt Island. The caves on De Witt Island were first noted by Nigel Brothers, in 1986, and his descriptions provided the incentive for this investigation. Owen Barrett, lightkeeper on Maatsuyker Island, assisted with radio communications during our inclement weather confinement on the island. Carole Edwards is thanked for drafting the figures. GD completed this study whilst undertaking a project, Geoheritage Inventory of Tasmanian Islands, funded by the 1995/96 National Estate Grants Programme.

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(accepted 14 February 1996)

TERRESTRIAL DEVELOPMENT IN THE TASMANIAN FROG, *BRYOBATRACHUS NIMBUS* (ANURA: MYOBATRACHINAE): LARVAL DEVELOPMENT AND A FIELD STAGING TABLE

by Nicola Mitchell and Roy Swain

(with three tables and one text-figure)

MITCHELL, N. & SWAIN, R. 1996 (30:vi): Terrestrial development in the Tasmanian frog, *Bryobatrachus nimbus* (Anura: Myobatrachinae): larval development and a field staging table. *Pap. Proc. R. Soc. Tasm.* 130(1): 75–80. Department of Zoology, University of Tasmania, Box 252C, GPO Hobart, Tasmania, Australia 7001.

The moss froglet *Bryobatrachus nimbus* is a recently described terrestrial breeding and direct developing anuran from southwestern Tasmania. A 17-stage table based on changes in external morphology was developed in order to calculate development rates and larval lifespan. This staging demonstrated that development was not predominantly intracapsular as earlier reported. Instead, larvae hatch from the capsule two to three months after oviposition and continue development in the nest within a homogenous, capsule-derived fluid. This reproductive mode was previously known in Australia only in the *Geocrinia rosea* complex from southwestern Australia. This paper describes the larval life-history of a subalpine population and presents data on clutch size, ovum and capsule diameters and the duration of larval development. Capsule size is almost twice that recorded for any other Australian anuran, while the larval lifespan is the longest known for any terrestrial breeding Australian species. Metamorphosis occurs approximately 12 months after oviposition.
Keywords: Amphibia, *Bryobatrachus*, direct development, life history, staging, terrestrial breeding, Tasmania.

INTRODUCTION

The moss froglet, *Bryobatrachus nimbus* Rounsevell, Ziegeler, Brown, Davies and Littlejohn, 1994, was discovered late in 1992, following the reporting of an unusual frog call in heathland at several high altitude sites in southwestern Tasmania (Rounsevell *et al.* 1994). It is the first addition to the Tasmanian anuran fauna since the description of the Tasmanian Tree Frog, *Litoria burrowsae* (Scott 1942), and is only the third endemic species of the 11 Tasmanian anurans now known. Its discovery is significant, because both the habitat occupied and the reproductive mode exhibited are unique amongst the local fauna and are shared by very few mainland Australian species.

Bryobatrachus nimbus inhabits cloud-forest in subalpine heath and lowland rainforest in the wet southwest of the island and is the sole Tasmanian anuran in which the life cycle is entirely terrestrial. The adults are cryptic, and females deposit small clutches of large eggs in nests built into moss, lichen or peat in a spring/summer breeding season; larvae complete development in the nest without feeding and are direct-developing (Rounsevell *et al.* 1994).

Staging tables are useful in ascertaining the rate and duration of larval development, both of which were unknown for *B. nimbus* at the commencement of our study. Stages 20–26 of the standard anuran staging table developed for aquatic species by Gosner (1960) are not applicable to any myobatrachine in which the life history has been described, since these all lack external gills and exhibit differences in the development of the eye and oral suckers (Gollman & Gollman 1991). Furthermore, the large yolk sacs characteristic of direct developing species can mask some of the stages defined by Gosner (Gollman 1991). De Bavay (1993) has produced a meticulous staging table for the limnodynastine *Kyarranus sphagnicolus*, which follows Gosner's scheme to Stage 19 and redefines and reduces the numbers of stages thereafter.

We have developed a simple 17-stage table based on external features (visible to the naked eye or under low magnification), as a means of staging larval development in *B. nimbus* under field conditions, and have used this table to determine rates of development in both field and laboratory conditions. We also describe the larval life-history of *B. nimbus* and report data on clutch size, ovum and capsule diameters and the duration of larval development in a subalpine, heathland population.

METHODS

Study Site

The study site was the type locality of *B. nimbus* in the Hartz Mountains National Park. It consists of a poorly drained, subalpine moorland at 900 m, immediately north of Lake Esperance, and covers approximately 5 ha. This site contains the only readily accessible population of the 15 populations reported by Ziegeler (1994). Vegetation communities and climatic patterns have been described by Rounsevell *et al.* (1994). In the period 2/10/94 to 29/2/96 approximately 40 visits, each of 1–3 days duration, were made to the site.

Staging of Larvae

Two clutches of ten eggs newly deposited in December 1994 were transported intact in their moss nests to the laboratory in Hobart. Clutches were transferred to glass petri dishes, sprayed with distilled water and placed in a glass desiccator and maintained at 16 (±1)°C. Manually controlled lighting provided a photoperiod regime of approximately 12 h light: 12 h dark. Larvae were sprayed twice weekly with distilled water; at front limb emergence they were provided with substrate (moistened paper towel) and immersed in amphibian Ringer's solution (Hoar & Hickman 1975).

Larvae were photographed using a 35 mm camera attached to a Zeiss Stemi SV11 stereo microscope, initially twice-weekly, and after longer intervals as development progressed. Individual larvae were periodically selected to illustrate stages, killed by an overdose of MS222 and preserved in Tyler's fixative (Tyler 1962). Drawings of preserved specimens were made from observations through a stereo microscope. Examination of these specimens, and analysis of photographic records and developmental notes from field and laboratory-reared larvae allowed the identification of 17 distinct stages. Only those stages that could be reliably determined by the naked eye or by a low power lens were used to develop the staging table, although numerous intermediate stages could be identified in the laboratory.

Measurement of Clutch, Ovum, Capsule and Larval Size

All clutches located in the field were marked by tagging adjacent vegetation; the number of visible eggs or larvae was counted and larval features described. Eggs were not handled, in order to eliminate human interference as a cause of mortality; hence, only surface eggs were counted and described. In order to correct for underestimates of clutch size, the number of eggs in eight clutches that were removed for laboratory studies was estimated in the field and, subsequently, compared with the number determined by laboratory examination. This revealed that clutch sizes were underestimated by between one and four eggs; to provide more realistic estimates of clutch sizes, field counts were adjusted as follows: one egg was added to estimates of eight eggs or fewer, and two eggs were added to all larger estimates. Occasionally, we were confident that we could see all the eggs in a clutch, and these estimates were not adjusted. Clutches discovered after capsule degradation were not included in the estimates of clutch size, as larvae had often sunk to the base of the nest and were difficult to discern.

Accurate measurements of ovum and larval size could only be obtained in the laboratory; they were made by using a stereo microscope and an eyepiece micrometer, under either distilled water or Ringer's solution, according to their stage. Larvae reared at 11, 16 and 21°C were measured every three to four days. Size at each stage was determined from larvae reared at 11 and 21°C. Embryos were measured along their maximum axis and, beyond Stage 9, snout-vent lengths were also obtained. Capsule diameters were measured to Stage 10, since some tadpoles remain within the capsule to this point.

Vernier callipers were used in the field to measure external capsule diameters of newly deposited eggs to the nearest 0.05 mm, especially if eggs were particularly accessible or of an extreme size. Ovum and capsule diameters of six newly deposited clutches were measured in the laboratory on the same evening that they were removed from the field.

Length of the Larval Period

Most clutches discovered were re-examined at each extended field visit; in this way development rates and the length of the larval lifespan could be determined.

RESULTS

Field Staging Table

Table 1 lists the diagnostic features of each of the 17 stages identified for *B. nimbus,* while figure 1 illustrates these stages. Some features of several stages can only be identified with the aid of a hand lens, but broader characteristics, such as a typical posture, should allow the identification of any stage in the field. Onset of heartbeat (Gosner Stage 19) and blood circulation in the tail become apparent between Stages 11 and 12 and Stages 12 and 13 respectively and, thus, were not used as diagnostic criteria. Adult *B. nimbus* exhibit three pairs of distinct dark-brown or black dorsal markings; the first pair fuses between the eyes (chevron shaped), and two other pairs occur in the scapula and coccygeal regions respectively (Rounsevell *et al.* 1994); these are the markings referred to at Stage 15 in table 1.

In most respects, developmental stages of *B. nimbus* parallel those determined by de Bavay (1993) for *Kyarranus sphagnicolus*. To facilitate comparison, table 1 identifies the correspondence between stages in *B. nimbus* and *K. sphagnicolus.*

Mean sizes at all stages of larval development are listed in table 2. Larvae in the 11°C treatment were not retained beyond Stage 11, because of concern about maintaining larvae in artificial conditions for an indeterminate period. Sizes for later stages were derived from the faster developing larvae maintained at 21°C (table 2). The rate of laboratory development at 11°C was comparable to development rates in the field (N. Mitchell, pers. obs.). The measure of larval size was dependent on the posture of each individual, and variability in posture was pronounced during the stages prior to capsule degradation (Stages 7 to 10). Hence, the variance estimates of larval length increase beyond Stage 6.

Ovum, Capsule and Clutch Size

Of 62 clutches in which egg number could be counted, estimates of clutch size ranged from 4–16 eggs (mean ± SE = 9.1 ± 0.39). Table 3 shows egg number, together with mean ovum and mean external capsule diameters for six of the eight newly deposited clutches that were returned to the laboratory. Capsule diameters were quite variable, both within and between clutches, presumably due in part to differences in hydration state, but it is clear that the eggs of *B. nimbus* are characterised by the provision of a large egg capsule (table 3).

Description of Larval Development

Bryobatrachus nimbus clutches were located throughout the period November 1994 to March 1995. With the single exception of a nest built into peat beneath lichen, all clutches were found in small nests (20–70 mm in diameter) concealed within moss. Usually most eggs were distributed in a single horizontal surface layer overlying a few eggs that filled the nest base. As development progressed, individual egg capsules lost their integrity and their horizontal diameter increased. Eventually, the seams between capsules vanished and a homogenous gelatinous mass was formed. Larvae would then sink to the base of the nest.

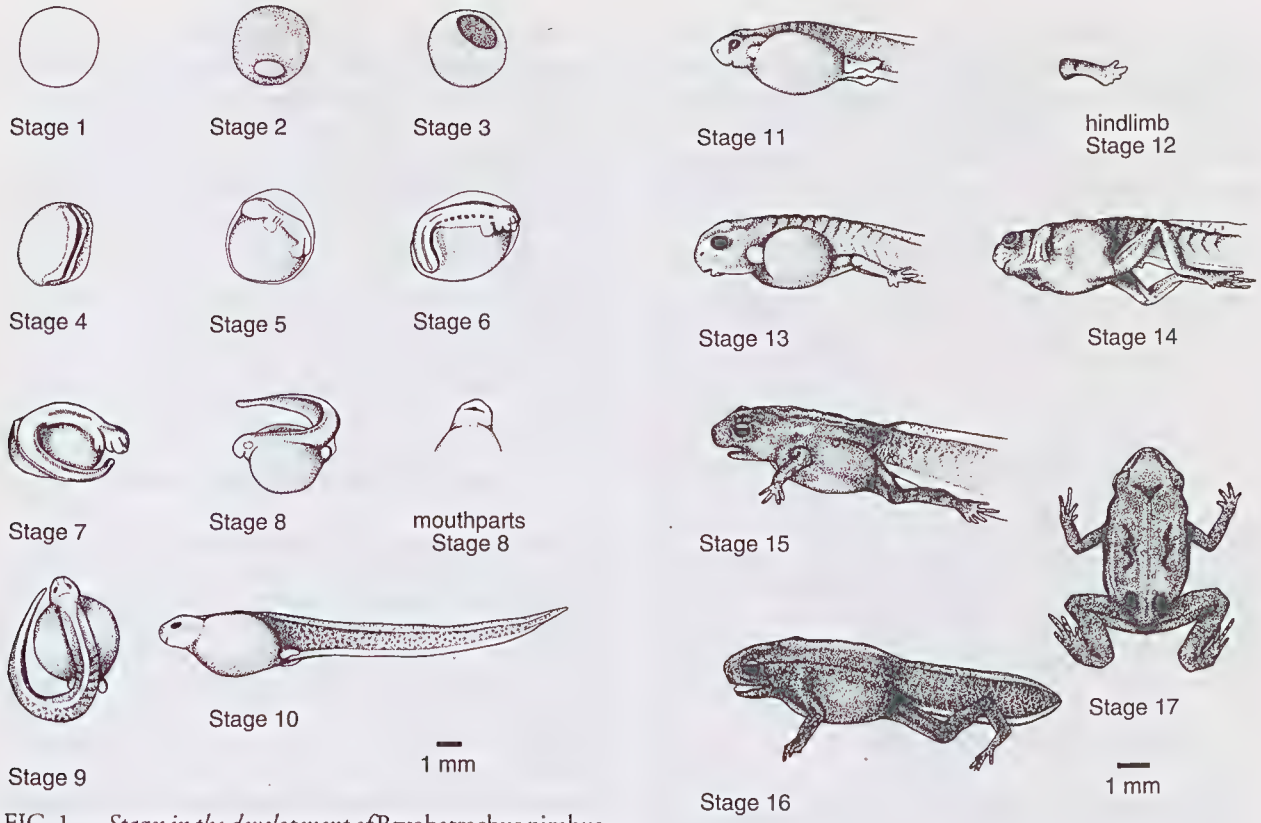

FIG. 1 — *Stages in the development of* Bryobatrachus nimbus.

TABLE 1
Stage descriptions of larval *Bryobatrachus nimbus*

Stage*	Diagnostic features	de Bavay equivalent
1	• stage begins at oviposition • egg unpigmented - cream or grey-cream; surface featureless	1-7
2†	• mid-late gastrula • egg grey, with cream poles	8-10
3†	• yolk-plug developed • egg grey/cream, with dark poles	11-12
4†	• neural folds form to outline neural plate • vitellus slightly ovoid	13-15
5	• embryo visible as a ridge on egg surface • tail rudiment and somites† visible • vitelline membrane† distinct	16-17
6	• embryo length exceeds egg diameter • head well differentiated • tail about as long as and bent 90 ° to body	18
7	• tail usually curled around yolk; about twice length attached body • anal pore† evident • capable of strong writhing	19-19b
8	• Larvae "C" shaped; tail no longer flush to yolk; about 2.5 times length of attached body • paired, circular hind buds prominent • opaque tail fin formed • mouthparts† just visible • vitelline membrane may not be intact	20-22
9	• grey eye pigmentation developing • hind buds ovoid • mouthparts† distinct • vitelline membrane broken down • larvae may be free of capsule	23-24b
10	• tail 3.5 x SVL‡; tail straight; larvae free of capsule • yolk-sac vanished (incorporated into body) • eye appears entirely black • hind bud expanded to a "paddle"† • larvae may be free of capsule	25-26
11	• eye "surfaced" • nostrils† just visible • digit indentations† developed on hind buds; buds similar length to head • small front limb swellings† • tail reticulation† developing • larvae free of capsule	27-28
12	• individual digits discernible on hind limb • upper half of iris† gold	29-30
13	• distinct bend to hind limbs • front bud swellings prominent • tail reticulation† pronounced	31-32
14	• prominent front limb bulge; digits† visible beneath skin • pronounced bend to hind limbs; total bent-leg length similar to SVL‡	33
15	• front limbs emerged • dorsal spotting developing • characteristic dark dorsal marks† developing	34
16	• dorsal colouring developing • tail re-absorption occurring	35-36
17	• tail completely reabsorbed • adult colours emerged • dorsal spots vanished or vanishing	37

* Larvae have reached a developmental stage when 50% of the diagnostic features of that stage have become evident (de Bavay 1993).
† Indicates stages or features requiring low power magnification for identification. ‡ Snout vent length.

TABLE 2
Dimensions of ova, larvae and capsules, and snout vent length (SVL) of *Bryobatrachus nimbus* larvae at each stage

Stage	Mean ovum or larval length (mm)	SE	Mean SVL (mm)	SE	Mean capsule diameter (mm)	SE	*n*
1	3.9	0.11			11.3	0.30	18
2	4.3	0.06			NA		
3	NA				11.8	0.31	18
4	4.3	0.06			12.7	0.31	18
5	4.8	0.05			13.4	0.30	19
6	5.6	0.08			14.0	0.39	18
7	7.6	0.19			16.1	0.60	17
8	8.6	0.26			17.7	0.61	18
9	9.4	0.16			21.2	0.81	16
10	10.0	0.21	4.7	0.07	22.5	0.72	16
11	16.5	0.26	5.0	0.07			15
12	*17.3	*0.38	*5.0	*0.10			*10
13	20.2	0.40	5.9	0.07			13
14	*18.4	*0.42	*5.2	*0.07			*8
15	*17.9	*1.29	*5.9	*0.13			*8
16	*13.1	*2.17	*6.3	*0.16			*8
17			*7.1	*0.32			*8

* identifies measurements from larvae developing at 21°C; all other measurements are from development at 11 °C.
NA = measurement not available.

TABLE 3
Clutch sizes, ovum and capsule diameters of six clutches measured in the laboratory at Stage 1 or 2

Clutch number	Clutch size	Mean ovum diameter (mm)	SE	Mean capsule diameter (mm)	SE	*n**
1	12	4.2	0.10	11.3	0.38	9
2	10	3.6	0.13	11.4	0.51	8
3	12	4.2	0.05	11.4	0.25	12
4	10	4.1	0.04	13.8	0.28	10
5	11	4.0	0.07	9.6	0.39	9
6	10	4.4	0.06	10.9	0.21	9
Mean	11	4.1	0.05	11.4	0.21	Σ57

* *n* refers to the number of eggs that were included in the calculation of mean egg and capsule diameters.

The volume of capsular fluid fluctuated during development. Nests examined during dry weeks in summer sometimes contained less than 5 mm depth of fluid while, in the same nest, capsular fluid would swell and fill the nest after heavy rain. Larvae usually remained at the base of the nest but were occasionally discovered on the fluid surface. At metamorphic climax, only a smear of capsular fluid remained in the nest; metamorphs were often positioned vertically on the nest wall with their tails dangling in the fluid, or else piled upon each other at the nest base. Metamorphs would remain in the nest after tail reabsorption was complete (Stage 17) for 1–2 weeks. Occasionally larger metamorphs were discovered in nests, up to several months after the original metamorphs had vanished.

Early development of eggs (Stages 1–8) was rapid; larvae could be found in these stages between December and March. Nests were frequently under snow during autumn and for much of winter, and development was negligible during this period. Most larvae overwintered at Stages 9–11. Development rates did not accelerate until late spring and early summer, when metamorphic climax was approached comparatively rapidly. For example, 11 individuals of a clutch of 13 observed at Stage 12 on 5/1/95 had almost completed metamorphosis (Stage 17) 27 days later on 1/2/95. Ten froglets left this nest within five days, while one individual was still in the nest on 17/2/95, having recently metamorphosed.

Length of Larval Development

The larval lifespan of *B. nimbus* approximates 12 months. Exact periods of larval development in the field were difficult to determine, as most clutches discovered soon after oviposition were removed for laboratory study, whilst precise dates of metamorphic climax for the remaining clutches were not obtained, due to infrequent field visits in the 1995/1996 breeding season. However, a froglet from a clutch discovered at Stage 2 on 22/12/94 was approaching metamorphic climax (i.e. Stage 16) on 7/1/96, indicating a larval life in excess of 12 months. The simultaneous presence of freshly deposited clutches and metamorphs from December to February further supports this conclusion.

DISCUSSION

Numerous authors have commented upon the remarkable diversity of reproductive modes within the Myobatrachinae (e.g. Littlejohn *et al.* 1993, Rounsevell *et al.* 1994). Our study provides yet further support for this conclusion; *Bryobatrachus nimbus* lies midway along a spectrum of differing degrees of intracapsular development, exemplified at one extreme by the part intracapsular/part aquatic development of most species of *Pseudophryne* (Jacobson 1963) and at the other by the completely intracapsular development of *Arenophryne* (Roberts 1984) and *Myobatrachus* (Roberts 1981).

However, *B. nimbus* larvae do not undergo intracapsular development to the extent suggested by Rounsevell *et al.* (1994); hatching occurs well in advance of metamorphosis (around Stage 10), at about the same stage as in the *Geocrinia laevis* complex and later than aquatic developing *Crinia signifera* larvae (Gollman 1991). The consequence is that 9–10 months of development in *B. nimbus* is spent as a free-living but non-feeding tadpole within the capsule fluid. Of 29 anuran reproductive modes defined by Duellman & Trueb (1994), *B. nimbus* fits mode 15: "eggs hatch into non-feeding tadpoles that complete their development in the nest". Duellman & Trueb (1994) recorded this mode in six species: one leptodactylid and one microhylid from South America, and one bufonid and three ranids from Africa, but it is also known for the *Geocrinia* spp. from southwestern Western Australia (Main 1957, Roberts *et al.* 1990). Rounsevell *et al.* (1994) also drew attention to morphological similarities between larval *B. nimbus* and the larvae of two species of the *Geocrinia rosea* complex, *G. rosea* and *G. lutea*.

The apparent restriction of *B. nimbus* to moist, cloud forest habitat (Ziegeler 1994) is consistent with the general, although not exclusive, correlation observed between terrestrial reproductive modes in the Anura and habitats of high atmospheric humidity (eg. Martin 1967, Duellman 1985). It is, presumably, a consequence of the need to retain some moisture within the nest at all times during the prolonged period of larval development. Although southwestern Tasmania experiences an average annual rainfall of 2500 mm (Gentilli 1972), much of the area may be dry for weeks at a time in summer (Swain *et al.* 1988). In these circumstances, a large egg capsule may provide valuable insurance against larval desiccation, and mortality of larvae contained within smaller capsules was certainly higher than in those within larger capsules, during a period of consistently dry weather in January/February 1994 (N.Mitchell, pers. obs.). However, a large capsule volume is likely to have other important consequences, perhaps in relation to cold tolerance but particularly for larval respiration. Respiration rates in developing anurans are strongly influenced by the oxygen conductance of the capsule jelly; conductance is determined by the permeability of the jelly, which is about 75 % of that of pure water at the same temperature, and its thickness and surface area (Seymour & Roberts 1995).

Several staging tables based on modifications of that of Gosner (1960) have been developed for myobatrachines: *Pseudophryne* (Jacobson 1963, Woodruff 1972), *Crinia* (Gollman 1991), *Geocrinia* (Gollman & Gollman 1991), and *Kyarranus* (Watson & Martin 1973, Anstis 1981). However, these are not useful under field conditions, either because illustrations are not provided for the stages that diverge from those identified by Gosner (1960), or because insufficient detail on external morphology is presented. Although the construction of our staging table was motivated by the need to identify stages under field conditions, and the table is not primarily intended for comparative studies, sufficient observations were made to conclude that the developmental morphology of *B. nimbus* closely parallels that detailed by de Bavay (1993) for the limnodynastine *Kyarranus sphagnicolus*, a foam-nesting species with a similar life history. A modified version of de Bavay's staging could be used in the laboratory for *Bryobatrachus*, but it is not helpful for fieldwork. Because *B. nimbus* is non-feeding and lacks a mouth disc, particular difficulties are likely in the interpretation of Stages 24b–26 and 34 of de Bavay (1993) which utilise the development and disappearance of the prominent horny jaws of *K. sphagnicolus*.

Terrestrial anuran larvae have generally retained the morphology of the free-swimming, feeding ancestral larvae (de Bavay 1993), although morphological divergence, such as the atrophy of feeding structures and the development of supplementary respiratory surfaces, can be pronounced in some direct-developing species (e.g. *Eleutherodactylus coqui* [Townsend & Stewart 1985]). *Bryobatrachus nimbus* larvae appear to possess both kinds of adaptation, since they cannot feed and the long vascularised tail may act as a respiratory surface. In addition, *B. nimbus* exhibits some additional characteristics commonly found in direct-developing larvae: the absence of egg pigmentation (Duellman & Trueb 1994) and encapsulation in the vitelline membrane well into development (Salthe 1963).

In summary, we conclude that, while the reproductive mode employed by *B. nimbus* is rare but not unique within the global amphibian context, the combination of individual reproductive parameters is distinctive and does not occur in any other Australian species. The most unusual characteristics of larval development in *B. nimbus* are the large egg capsules and the year-long terrestrial larval development period. Larval development times of other populations of *B. nimbus*, located from calling surveys (Ziegeler 1994) are unknown but, given that *B. nimbus* occurs across an altitudinal range of 30–1100 m (Ziegeler 1994), it would be interesting to determine to what extent larval lifespan is temperature mediated. Our staging table will enable the length of larval development times in other populations of this unusual frog to be determined.

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(accepted 14 May 1996)

ADDITIONAL RADIOCARBON DATE FROM DANTE OUTWASH FAN, KING VALLEY, AND DATING OF THE LATE WISCONSIN GLACIAL MAXIMUM IN WESTERN TASMANIA

by Eric A. Colhoun and Sean J. Fitzsimons

(with one table and two text-figures)

COLHOUN, E.A. & FITZSIMONS, S.J., 1996 (30:vi): Additional radiocarbon date from Dante outwash fan, King Valley, and dating of the late Wisconsin glacial maximum in western Tasmania. *Pap. Proc. R. Soc. Tasm.* 130(1): 81–84. ISSN 0070–4703. Department of Geography, University of Newcastle, Callaghan, NSW, Australia 2308 (EAC); and Department of Geography, University of Otago, PO Box 56, Dunedin, New Zealand (SJF).

A radiocarbon date of 19 100 ± 100 yr BP (SUA 2856) closely dates the maximum extent of glacier ice at Lake Beatrice in the upper Dante Rivulet during the Late Wisconsin in western Tasmania. Study of the Dante Glacier outwash fan deposits shows that they overlie a palaeosol and an older outwash gravel formation, and are interstratified with fluvial silts containing transported organic detritus deposited by flooding of the King River. Examination of available radiocarbon dates obtained from the palaeosol and interstratified silts shows that the palaeosol, Dante outwash and fluvial silt sequence was formed during a relatively short period preceding and around the peak of the Late Wisconsin glacial stade (18–20 kyr BP). The data suggest that the Dante Glacier extended to its end moraine limits for only a short time.
Key Words: glacier ice, outwash, palaeosol, Dante Formation, Tasmania.

THE DANTE SECTION

During the Late Wisconsin glacial stade (<25 and >10 k yr BP) (locally the Late Margaret Glaciation), the West Coast Range of Tasmania acted as a snowfence east of which cirque and valley glaciers and a thin ice cap were developed on the Lake Dora plateau. The limits of these ice masses are defined by impressive end moraines at Lake Margaret in the southwest, by the Tyndall and Lake Rolleston moraines in the north, and by moraines adjacent to and south of Lake Beatrice in the upper part of the Dante Rivulet valley (Colhoun 1985, Kiernan 1980) (fig.1). Outside the Lake Beatrice moraines, a large outwash fan adjacent to Dante Rivulet extends to the western bank of the upper King Valley and, prior to the flooding of Lake Burbury, the outwash deposits were exposed in a section of c. 300 m length on the west bank, half a kilometre downstream of the confluence of the Dante Rivulet and King River, and at 230 m altitude (145°40'30"E and 42°3'30"S; Grid ref. 894 451 on Franklin Sheet 8013 Series R661, 1:100 000 Topographic Survey, Australia). The section varies in height from c. 5–10 m as seen in figure 2, where the stratigraphic column described by Gibson *et al.* (1987) occurs 100 m south of that described in this paper. The section exposes the most important sequence of deposits found so far for dating the maximum Late Wisconsin ice extent in Tasmania.

The stratigraphic column described by Kiernan (1980) and Gibson *et al.* (1987) (fig.2) showed a lower outwash gravel that was initially assigned to the Comstock Formation (Kiernan 1980, 1983), because of its stratigraphic position and geographic location, but which, because of the relative lack of weathering rinds on igneous rock clasts, was noted by Gibson *et al.* (1987) as possibly being younger. Further investigations by Fitzsimons *et al.* (1992) indicated that this lower outwash gravel was probably part of the Chamouni Formation formed by an ice advance that postdated the Comstock Formation of the Penultimate or Henty Glaciation and predated the Dante Formation of the Late Wisconsin Margaret Glaciation in the West Coast Range–King Valley region. The Chamouni ice advance is tentatively assigned to the Early Wisconsin cold stade (for definition of formations and glaciations (see Fitzsimons *et al.* 1992: 9, Table 2).

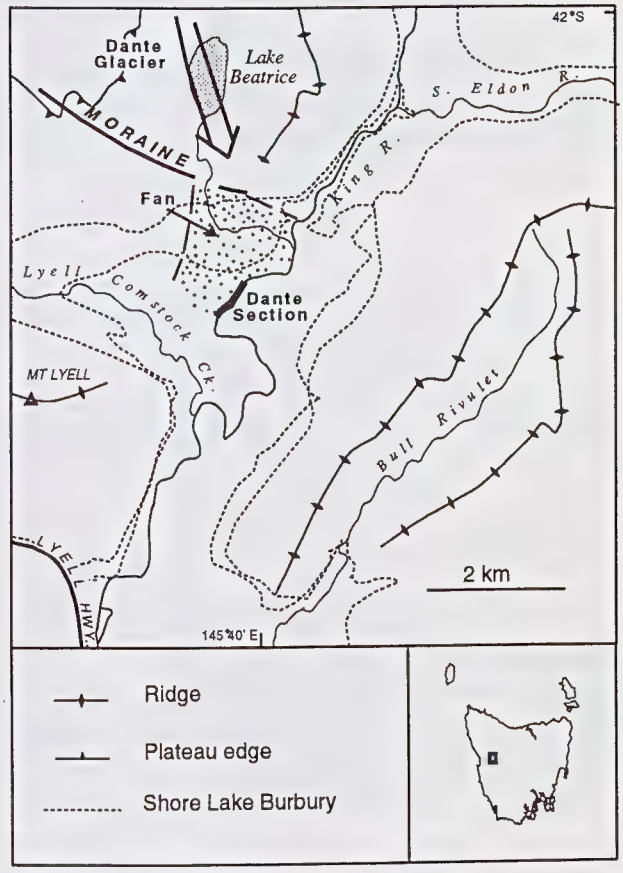

FIG. 1 — Location of the Dante Section in the upper King Valley, the Dante outwash fan and Lake Beatrice end moraines.

The lower outwash is overlain by a thin horizon of organic silt with a distinct surface alpine-humus palaeosol including roots of plants and cushions of *Donatia novae-zelandiae* in growth position. The large *Donatia* shown in Gibson *et al.* (1987, Plate 1) was buried in flowering condition by a thin bed of silt and fine sand that contained drifted wood fragments and was formed in an aquatic environment. The silt, palaeosol and overlying fluvial silt and fine sand were formed during the King Interval, the time succeeding the glaciation that formed the lower outwash and preceding the Dante ice advance that formed the upper outwash. The Dante Formation was shown to consist of a bed of fine sand and silt overlain by c. 3 m of outwash gravel.

NEW DATA

Re-examination of the deposits described by Gibson *et al.* (1987) and examination of the thickest sequence of deposits about 100 m upstream provide stratigraphic column 2 (fig.2) and allow further interpretation of the origin of some of the deposits. The observations confirm the stratigraphy and origin of the sediments in the lower part of the sequence as consisting of an outwash sand and gravel that is of post Comstock and pre-Dante age, that could relate to retreat of the Chamouni ice advance of Fitzsimons *et al.* (1992). The observations also indicate that the silt and fine sand beds beneath and above the palaeosol containing the *Donatia* are stratigraphically continuous throughout the section. The interpretation that the silt and fine sand bed overlying the palaeosol was deposited in an aquatic environment is confirmed. It is suggested that this bed and the silt bed underlying the palaeosol were deposited by overbank flooding of the King River, and that the wood and charcoal fragments were drifted into position from proximal sources upstream. The fine sand and silt bed shown in column 1 as proglacial is inorganic and finely laminated and does appear to be proglacial. It lenses out northward and does not extend to the site of column 2. The overlying Dante outwash sequence commences at 1–1.05 m above the base of column 2. The beds of outwash sand and gravel are interstratified with beds of silt and fine sand that are frequently organic, and are of fluviatile origin.

The interstratified sequence consists of 23 litho-stratigraphic units with a total thickness of c. 8.3 m. Thirteen of the units are shown in column 2, which had to be condensed, as some beds are too thin to be shown (particularly in the upper part). The column is capped by 0.7 m of Holocene peat. The lithostratigraphic units of Dante outwash consisted of bedded inorganic sands, small pebbles and medium to coarse gravels composed of local Owen

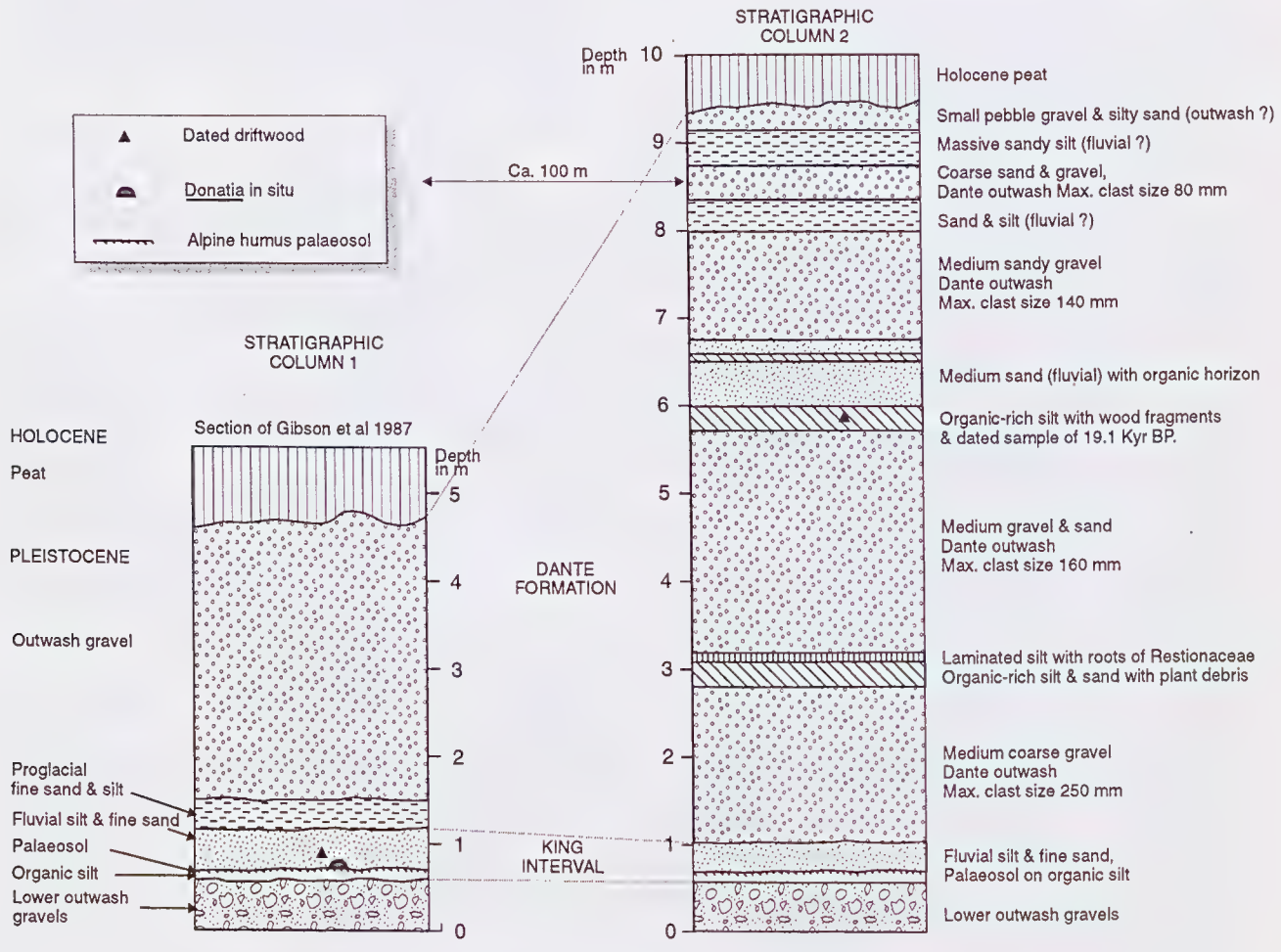

FIG. 2 — Stratigraphic columns showing the relationship of the outwash deposits of the Dante Formation to the alluvial deposits of the King River, the palaeosol and lower outwash deposit (after Gibson et al. *1987, Colhoun & Fitzsimons, this paper).*

Conglomerates and quartzite clasts derived from the conglomerate. In addition, there are unweathered volcanic clasts derived from the Mt Read Volcanics, that crop out north and west of the site, and Jurassic dolerites transported from Mt Sedgwick 5 km to the northwest, or derived from older glacial deposits that contain abundant Jurassic dolerites from the Mt Eldon area in the upper King Valley. The interbedded units of organic silt and fine sand containing finely divided charcoal fragments and drifted organic detritus contrast strongly with the inorganic outwash deposits. They are identical with overbank alluvial deposits that can be observed on the flood plains of western Tasmanian rivers and indicate deposition from repeated flooding of the upper King River catchment. Though interstratified with deposits of the Dante Formation they have a different origin and source.

Sedimentary evidence from the deposits in the Dante outwash fan allows some further interpretations of the extent and nature of the Dante ice advance and retreat. Firstly, the interstratified nature of the outwash and fluvial sediments shows that the site occurs in the distal part of the outwash fan and that the meltwater flows from the ice limit at the end moraines, south of Lake Beatrice, and overbank flooding, in the King Valley, were contemporary. The variation in thickness of columns 1 and 2 reflects the transverse convex surface of the outwash fan. The contrast between no interstratified alluvial silt and sand beds in the Dante Formation in column 1 and many in column 2 probably reflects the close proximity of a meander of the King River to column 2 during the period of accumulation of glacial outwash. In column 2 the maximum size of clast noted in the outwash gravel units decreases upwards from 250 mm through 160 mm, 140 mm, 80 mm to 20–30 mm. This indicates a gradual loss in competence of the transporting agent and implies either retreat of ice from the end moraine during deposition of the fan or reduction in meltwater velocity. Either way the sedimentary evidence indicates that the outwash fan was built after the ice had attained its maximum limit, south of Lake Beatrice, which is the maximum extent of ice of the West Coast glacial system.

DATING AND SIGNIFICANCE OF THE DANTE SITE

The Dante Site in the upper King Valley is the only site in Tasmania, or in Australia, having regard for the limited extent of glaciation in the Mt Kosciusko region, where the maximum extent of ice during the Late Wisconsin can be dated by virtue of the interstratification of the outwash sands and gravels with contemporaneous fluvial deposits. Elsewhere in Tasmania, radiocarbon dated sediments in cirque lakes occupied by ice or associated with moraines formed during the Late Wisconsin mainly postdate ice retreat. The oldest date of 17 700 ± 400 yr BP (SUA 1359) occurs in the cirque basin of Ooze Lake, at 880 m altitude in southern Tasmania. The oldest date of 13 400 ± 600 yr BP (SUA 2188) for northern Tasmania was obtained near the base of lake sediments inside an end moraine, at 575 m altitude at Dublin Bog in the Mersey Valley. In western Tasmania, the oldest dates that mark the commencement of post last glaciation organic sedimentation occur in a bog and lake that lie outside the Late Wisconsin ice limits. The dates are 13 010 ± 130 yr BP (SUA 2723) at Governor Bog (180 m altitude) in the middle King Valley and 14 200 ± 230 yr BP at Lake Selina (516 m altitude) in the West Coast Range (Macphail & Colhoun 1985, Colhoun *et al.* 1991a, Colhoun *et al.* 1991b, Colhoun *et al.* 1996).

The dates obtained by Kiernan (1980) and Gibson *et al.* (1987) from the Dante Site closely predate the extension of ice to its maximum limit south of Lake Beatrice and the deposition of the Dante outwash fan but they do not date it (table 1)

Pollen and macroscopic plant evidence obtained by Gibson *et al.* (1987) from the alluvial silt underlying the palaeosol and 100 m downstream of column 1 showed that the environment was cold and comparable with the modern

TABLE 1
Radiocarbon dates from the Dante Site, western Tasmania

Lab. no.	Date 14C yr BP	Comment
SUA 2856	19 100 ± 100	Wood fragment from alluvial silt c. 5.8 m above base column 2
ANU 2533	18 800 ± 500	Wood fragment from alluvial silt c. 0.8 m above base column 1
SUA 2154	21 180 ± 370	*Donatia* bolster c. 0.75 m above base column 1
SUA 2155	20 100 ± 470	Twigs in alluvial silt 100 m downstream of column 1 and below palaeosol on which *Donatia* grew

alpine zone prior to formation of the palaeosol and emplacement of the Dante outwash. *Donatia* bolsters are normally characteristic of the alpine zone above 1000 m and their presence supports the interpretation of cold alpine conditions for formation of the humic palaeosol. The dates of 20.1 kyr BP and 21.18 kyr BP are not significantly different at 2 σ (i.e. standard deviations). Thus, the palaeosol must have been formed rapidly after deposition of the silt.

The radiocarbon date on the small piece of driftwood from the fluvial silt 0.1 m above the palaeosol and 0.8 m above the base of column 1 dated by Kiernan (1980) to 18.8 kyr BP is not significantly different from the silt underlying the palaeosol but is significantly different from the age of the *Donatia* at 2 σ, though the difference is small. Kiernan regarded this date of 18.8 kyr BP as dating the maximum ice advance but, as the fluvial silt underlies the proglacial fine sand and silt in column 1, it must slightly precede the maximum. The new date of 19.1 kyr BP obtained on wood from fluvial silts interstratified within the main body of the Dante outwash gravels is not significantly different at 1 σ from the date obtained by Kiernan immediately below the outwash. The date confirms that the maximum ice advance of the West Coast glacial system to the moraines south of Lake Beatrice, during the Late Wisconsin cold stade, occurred at 19.1 kyr BP. The nature of the interstratified sediments and the location of the new date above the middle of the outwash sequence suggests that the outwash fan was deposited rapidly and that the ice did not remain for a long time at the end moraines.

This 19 100 ± 100 yr BP (SUA 2856) date for the maximum Late Wisconsin ice extent of the West Coast glacial system of Tasmania is closely comparable with dates obtained for the Late Wisconsin stade in western New Zealand and in Chile. In Westland, South Island, New Zealand the Late Wisconsin cold stade is represented by the Larrikins Formation which was deposited by an ice advance that commenced somewhat before 22.3 kyr BP and culminated at c. 18 kyr BP, or a little later (Suggate 1990). In Chile, the Late Wisconsin maximum ice advance constructed end moraines around the western ends of several of the southern Chilean lakes along the foot of the Andes. Radiocarbon dating of the moraine sequences, particularly at Lago Llanquihue, shows that Llanquihue II moraine was formed by ice that advanced after 30 kyr BP and reached its maximum position between 20–19 kyr BP (Porter 1981). The comparison indicates that the maximum extension of ice during the Late Wisconsin cold stade in the three glaciated Southern Hemisphere mid-latitudes regions was closely equivalent and occurred between 20 and 18 kyr BP.

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